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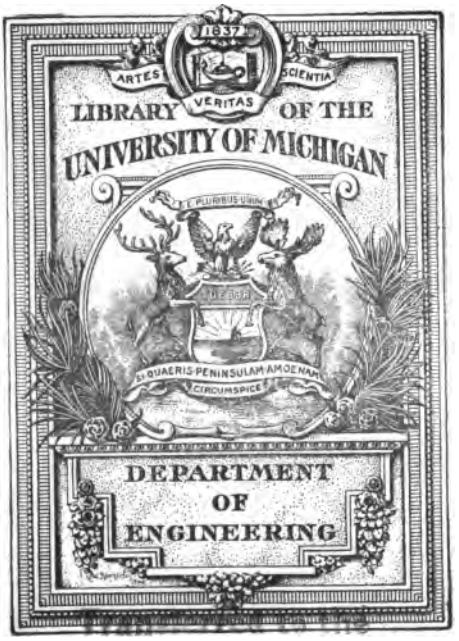

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PAPERS AND DISCUSSIONS

ON

IRON SHIPS.

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ON CAUSES OF UNSEAWORTHINESS IN MERCHANT STEAMERS.

By B. Martell, Esq., *chief surveyor of Lloyd's Register of British and Foreign Shipping, member of Council.*

[Read at the twenty-first session of the Institution of Naval Architects, March 17, 1880; the Right Hon. Lord Hampton, G. C. B., D. C. L., president, in the chair.]

The loss at sea of many steamers during the last few months, involving great sacrifice of human life and immense destruction of property, has drawn more than usual attention to questions of safety in the mercantile marine.

The probable causes of such calamities have been scanned from different points of view, and the possibility of more adequately providing against similar losses in the future has been strongly and rightly insisted on.

As too often has happened before, in many of the recent disasters, all hands have perished, so that no certain information has been obtainable to indicate the cause of loss, and we are therefore left to draw conclusions as best we can by deductions from general experience and circumstances, and the facts elicited from survivors who have been providentially saved from some of the vessels that have foundered.

Information of the latter kind would be invaluable if we could always depend upon its accuracy and on the absence of exaggeration. Few men, however, at moments of extreme danger, have either the coolness or the leisure to note correctly what is passing around, and whose memories can be trusted to convey afterwards an exact narrative. At least, that is my experience after many investigations. This it is which in a measure leads to so many conflicting opinions, as we see daily in the press and hear in shipping circles.

There are, however, some facts which stand out only too clearly as elements of danger, and to these I hope to draw your attention, as well as to some others of importance, though perhaps not in so great a degree. And I think I shall be able to show you that some important misconceptions exist as to the causes of loss, which create unwholesome prejudices and do positive injury by withdrawing attention from the real sources of evil. It will be well, perhaps, in the first place to run over a list of the several causes assignable for shipping disasters before discussing their relative importance.

We have then—

1. Weakness of structure from deficient scantlings, combined with faulty construction in arrangement and workmanship, together with inferiority of material.

2. Deterioration, causing local defects and unseaworthiness.

3. Absence of proper control over cocks, valves, and pipes connecting the engines and boilers with the sea. Also a want of proper arrangement of bilge-pump suctions, and of suction pipes from sea and bilge, whereby water, from inadvertence or carelessness, can be run from the sea into a vessel.

4. Faulty and deficient pumping arrangements, preventing the accumulated water being pumped from the wings in turn of bilge, after a vessel, from shifting cargo or other cause, has become inclined.

5. Breaking down of machinery, and the consequent falling off of the vessel into the trough of the sea.

6. Bad navigation—leading to collision or vessels running ashore.

7. Inefficient protection of openings in the deck.

8. Hasty and improper loading, particularly of grain cargoes in bulk, and deficiency of shifting boards or bulkheads, or other means to prevent cargo from shifting.

9. Disproportionate dimensions of steamers, combined with undue height of double bottom, thereby causing, with some description of cargoes, deficiency of stability.

10. Overloading.

Of the foregoing sources of danger it is not too much to say that all have, at some time or other, claimed their victims, but in connection with recent disasters special prominence has been given to the last three or four, and as a full consideration of all the causes I have named would extend beyond the necessary limits of this paper, I purpose dealing principally with these latter, while at the same time glancing briefly at the others in the order in which they are named.

1. As regards structural weakness and inferiority of materials used in building cargo-carrying steamers, much has been publicly said and written respecting this, both by those whom it was right to assume had some knowledge of the subject, and by others who had little or no acquaintance with ship construction, and the inference which some of these persons desired to have drawn respecting the unknown losses of many of these vessels was, that they broke in halves from inherent weakness and so disappeared in mid-ocean.

It may, however, be said that these conjectures are not founded on any *known* evidence, and that on the other hand, from the experience of hundreds of similarly-built vessels, as well as from scientific calculations, it is easy to show there was abundant structural strength—and, besides this, amongst the items of information which have been gathered from the unhappy survivors of some of these vessels which have foundered, there has not been a particle of evidence in this direction, but it has invariably pointed to other causes of disaster which will be hereafter alluded to.

From all the information I have been able to obtain from outside sources on this side of the Atlantic and the other, and from my own ex-

perience, and that of our large staff of surveyors, whose duty it is to carefully survey all classed vessels on their arrival home from foreign voyages, I am justified in stating emphatically that the causes of these recent losses must be sought elsewhere than in the want of structural strength.

2. That danger sometimes arises from local deterioration has been abundantly shown by experience, and the names of the *Magœra*, *Atlantic*, and others, will readily occur to every one in proof of this. It is also fully recognized that this danger has been rapidly diminishing since the practice of cementing the insides of iron ships has become universal and since it has equally become an object with every one to make all parts of the structure easily accessible.

Instances could, of course, be adduced where, owing to inferior cement being used, the plating of the bottom $\frac{8}{16}$ inch thick has been eaten through from the effect of a sugar cargo within six months from the date of launching.

I may instance that only within the last few weeks an iron vessel which had carried sugar cargoes amongst others was found to have as many as eighty of the iron floor-plates eaten through, and which had either to be renewed or made good by doubling plates.

The effect of galvanic action is also sometimes observed from the contact of copper pipes or roses with the outside plating, where the latter is not properly protected by cement.

All these instances I need hardly say show the importance of careful periodical surveys, particularly in vessels which were built before cement was generally adopted for the inside protection of the bottom plating.

3. As regards sea cocks, much might be said on this head. There is no doubt that the loss of many steamers have in the past arisen from an injudicious arrangement of cocks, valves, and pipes in connection with the machinery and the sea. We have only to remember the loss of the *La Plata*, and the narrow escape of the *L'Amérique*, and other vessels which could be named, which have mysteriously filled with water at sea, not to mention the cases of vessels which have filled and sunk in docks, to convince us that there have been, and still to some extent exist, silent dangers in the engine-rooms of steam-vessels, which require careful supervision.

This danger has, doubtless, within the last few years considerably diminished, as nearly all steamers now built have all cocks, valves, &c., in connection with the sea, fitted above the stoke-hole plates or platform, so that at all times they can be seen and kept in proper and safe working condition.

4. Much greater attention has been found to be necessary as to pumping arrangements, than was till lately thought requisite, so as to insure adequate means of pumping the vessel out by the engines at any angle of inclination in which she may be placed. It is of the greatest

importance that sufficient suction pipes should be led from the different compartments to the engine-room of steamers, and that these pipes should be connected not only to the bilge-pumps on the main engines, but to the donkey-pumps also, so that the whole of the steam-pumping power in the vessel may be applied whenever required. Where double bottoms are fitted for water ballast attention is also now paid to the arrangement of suction pipes, so as to enable any compartment to be wholly pumped out under any condition of the trim or position of the vessel. These have in past times been found common sources of inconvenience and of danger, for when a steamer was inclined and water had gathered in the bilges it was not always the case that proper suction pipes existed to enable the steam-pumping power to be used, and failing this the water has continued to accumulate until the fires were put out and there were no means of righting or saving the vessel. It is only right to add that in steamers now being built this subject is generally receiving very careful attention.

Fig. 1 (Plate I) shows a steamer having a deep tank for water ballast in the fore-hold, and double bottom for water ballast under the engine and boilers, and also in the after-hold. By the arrangement of suction pipes, sluices, and pumps it will be seen how water can be pumped from any compartment at any angle of inclination of the vessel, and it is only by such or a similar arrangement that water which may have found its way into a steamer can be entirely kept under control.

5. Breaking down of machinery.

The greater experience acquired in the management of steamers has forced upon owners and managers the necessity of a special and careful examination of the engines on the return of the vessel from every foreign voyage, and the employment of superintendent engineers, in order to avoid the risk of a break down, and the attendant consequences which may follow, not only in the loss of the vessel but of delay and cost in putting into a foreign port for repairs.

Too much importance cannot be attached to this, as from the great proportionate length of steamers now built, the smallness of sail power often provided, combined with the non-effectiveness of the rudder under sail alone while the screw-propeller remains attached, render it almost impossible to keep a vessel to any particular course, and hence the risk in falling off becomes enormous, with a low freeboard and small margin of stability. In having to encounter heavy seas under such circumstances, the danger can scarcely be magnified, and it arises perhaps from a slight casualty to the engines which by careful supervision before leaving port might have been obviated.

And here I may mention another point of great importance that leads to a similar danger to the foregoing, and has unfortunately led to many disasters. I allude to the too frequent breaking of rudder chains, or the disabling in other ways of the steering gear. Cargo steamers being often steered amidships from the bridge, the rudder rods and chains

have to be led long distances, and sufficient care may not be taken in fitting the sheaves properly for the rods to work over, or the leads for the chains may not be so fair as they should be.

At any rate, from one cause or another, accidents in this direction have happened too often, and when from want of sufficient propelling-power to keep her course safely, which is too often the case, a slow, deep-laden steamer has to adapt herself to a course safe and practicable; this position and her safety depend entirely on the rudder not being disabled.

The strains at such times brought on the chains and rods are very severe, and unless the material and workmanship be exceptionally good every blow from a heavy sea becomes a trying ordeal, for if anything should give way nothing can prevent the vessel from falling off into the trough of the sea and being placed in imminent peril. This has very recently been shown to arise even in one of the largest American liners. This vital part to the safety of cargo steamers is often, it is feared, paid less attention to than its importance merits.

6. Bad navigation, leading to collisions, or vessels running ashore.

On this point I am not called upon to speak professionally. Indeed, were it otherwise, I should not feel myself competent to do so before an audience composed largely of naval officers. But that bad navigation prevails, and prevails largely, we see from the records of collisions in our newspapers and law courts, and the numerous findings of courts of inquiry that vessels were run ashore through the neglect of soundings and other preventable causes.

At the same time my experience leads me to believe that the officers of the Mercantile Marine have considerably improved of late years. Whatever may be said to the contrary, the examinations they have to pass to obtain their masters' certificates tend to raise the educational standard among them, without impairing in the least their practical knowledge; on the contrary, a higher intelligence enables them more accurately to read the teachings of experience. It is fortunate that this is so, for as steamers grow in size and value from year to year the enormous value of the property and the number of lives committed to the charge of these men goes on increasing, as well as the difficulty of handling such monsters. When we come to consider other causes of loss arising from overloading and improper stowage it will be impossible to acquit shipmasters of all blame; but it must always be remembered of them that, whatever may be their faults of omission or of commission, they always risk and too often have to pay the penalty of their lives in return for their mistakes, whether they arise from ignorance or inadvertence.

7. I have mentioned the question of inefficient protection to engine and boiler openings and other openings in the deck, and this is one to which I have before drawn attention; but I fear due importance is not yet given to it. From want of due precaution in this, and in failing to

provide proper coverings for stoke-holds and fastenings for coal bunkers, pipes, or hatches, many losses I feel certain have occurred.

When we hear of the funnel and ventilators being washed away in some of our largest passenger steamers, with decks 10 or 12 feet above the water, what are we to expect if proper attention is not given to these vulnerable parts in deeply-laden cargo ships, with a freeboard in some instances not exceeding 4 feet?

Notes of warning have often been sounded in this direction, and the difference of these dangers in different trades has been insisted upon; but still the special requirements needed are often not realized or applied to the extent they should be.

The demand for cargo steamers during the last year or two for the trying Atlantic trade, and the generally-depressed condition of other trades, have caused many owners to send vessels across the Atlantic in midwinter, who doubtless would otherwise scarcely have thought such vessels suitable.

Perhaps it will tend to throw light on the development of steamers for the various cargo-carrying purposes if we glance at the earliest steamers so engaged and notice the alteration of types as they became increased in size and number.

The employment of steamers for special cargo-carrying purposes alone had its rise on the northeast coast for the coal-carrying trade, and from this type of vessel may be traced the various alterations throughout their development to adapt them to the general purposes of the trade for which they are now employed.

The earliest steam vessels built for the coasting trade were about 150 feet long, 25.6 broad, and 15.6 deep. The more recent vessels employed in this trade have been increased to 220 feet in length; the only alterations of importance made in the later vessels in addition to increasing their size being to increase their relative fullness of form; whilst the earlier vessels had a coefficient of tonnage fineness of .72, many of the later ones have increased in fullness to .77.

As the steam-carrying trade became developed, and steamers became built for longer voyages in the Baltic and Mediterranean, greater length was given than in the earlier vessels, while all the objectionable features of extreme fullness of form and flatness of floor were retained. Two principal causes doubtless operated to retain these features in cargo steamers.

In the first place it was thought the less the area of midship section to drive through the water under the same displacement, the less the propelling power required. And, secondly, that as steamers differed so widely from sailing ships in having no top-weight of heavy masts, and their stability consequently, when light, was so much greater, that there was less necessity to have a rise of floor to insure sufficient stability in shifting when discharged. Consequently the two great advantages were obtained in having a flat floor, viz, the reducing the

draught of water with the same displacement, and the carrying the greatest cargo under the same principal dimensions, whilst being able to place the engines and boilers as low as possible. The result of this has been to destroy nearly all beauty of architectural form in a large proportion of sea-going cargo steamers, by producing an approximation to a rectangular prism, whilst at the same time, as will be shown, it has at last been the means of introducing a positively dangerous element in this class of vessel.

The full, flat-bottomed form for steam colliers was no doubt the most suitable for the intended trade, as the result of great speed was not so profitable as carrying a relatively large cargo. Moreover, the fitting double bottoms throughout the fore and after holds was also most economical and safe for such vessels, seeing they always carried similar cargoes, and were found by experience to have sufficient stability either filled with coals or with water ballast alone. But it does not at all follow that vessels still further modified to suit general trades, where on one voyage they may carry iron ore stowed on the ceiling or inner bottom and on the return voyage may be quite filled with grain or other homogeneous cargo, can safely be built of similar proportions and form, and similarly fitted with water-ballast tanks throughout, as in their prototypes the colliers. The growth, however, of elements of unsafety in the design of sea-going cargo steamers can be clearly seen, and may, I think, be traced as follows:

If we take a vessel of the same length as one of those recently capsized, and trace the alteration of type under which such vessels have grown, from the flush decked collier to the fitting of a raised quarter deck and monkey forecastle, and subsequently the short poop, bridge house, and forecastle, and again the long poop or connection of poop and bridge house, extending from the stern to the front of the engine-room, and from this to the spar deck, and finally to the complete three tiers of beams, having the full scantlings to the gunwale, we shall be able to form an opinion of the relative safety of such types of vessels as regards their stability alone, under the various conditions of loading now in practice.

The vessels referred to, which recently capsized when loaded with cargoes of coal and grain, were all vessels having full scantlings to the upper deck, and were much alike in proportionate dimensions.

The following are the particulars of one of them:

	Feet.
Length	245
Breadth	33
Depth of hold	23

Vessels of the same length as above, and from which it may be said the latter type of vessel has arisen, have been built 245 feet long, 32 feet broad, and 17 feet 6 inches depth of hold, having a long raised quarter deck about 3 feet 6 inches above the main deck. Such a vessel

is shown in Fig. 2 (Plate I), and in fact illustrates one of this class of vessels now in existence. The draught of water when fully laden with coals, as indicated in the drawing, would be about 16 feet 3 inches, and by careful calculation it is found that the metacentric height would be 1.5 feet, so that such a vessel could be inclined to an extreme angle of 66° before arriving at the point of vanishing stability.

If we go further, and take a long poop vessel of the same length—that is, one having the poop and bridge-house connected—we shall find the dimensions of many such vessels now sailing to be, length 245 feet, breadth 32 feet, and depth of hold 17 feet 6 inches. The continuous erection on deck, 7 feet high, would be about 150 feet in length, and the forecastle about 30 feet. Such a vessel is shown in Fig. 3 (Plate II), and there is practically no difference in the principal dimensions from the preceding. With a cargo of coals below deck, and only a small portion in the poop, such a vessel would draw about 16 feet 6 inches of water; and in this case the metacentric height is found to be 1.5 feet, so that this vessel, with a homogeneous cargo, such as grain or coals, would have her maximum stability at 52°, and a considerable righting moment at 90° inclination.

By going a stage further we come to the spar-deck vessel. That is, one having the scantlings determined by the height to the main deck, and above this height the scantlings somewhat lighter. The dimensions of some of these vessels are—length, 245 feet; breadth, 32 feet, and depth of hold to spar deck, 24 feet.

Here the same beam is retained as in the former vessel, and the erection above the main deck is made continuous by a complete deck all fore-and-aft.

It is customary to load such vessels to within a short distance of the main deck, according to the structural strength, &c., of the ship, as shown in Fig. 4 (Plate II), thus leaving between 7 and 8 feet of freeboard from the spar deck.

The metacentric height of such a vessel loaded to this depth with grain or coals, assuming the hold to be filled and a portion only of the space to be filled between the main and spar decks, is found on calculation to be 0.8 feet, the angle of maximum stability being 55°, with a large righting force still in reserve at 90° inclination, owing to the high freeboard of this type of ship—thus showing, as in the preceding cases, that such a vessel would if loaded as described have an ample margin of stability.

Coming now finally to the vessel of the same length, and whose scantlings are continued of the full size to the upper deck, similar to the vessels referred to, which have recently capsized, and whose dimensions, as before stated, were, length, 245 feet; breadth, 33 feet; depth of hold, 23 feet, it will be observed that this vessel has one foot more beam than the spar-decked vessel, but a very striking difference will, at the same time, be apparent in the practice of loading this type of

vessel, as shown by the position of the load water-line in Fig. 5 (Plate II).

While the spar-decked vessel is supposed never to be loaded below the main deck, and consequently has the space between the main and spar deck only partially filled with cargo, the latter vessel is purposely increased in strength so as to admit of the main, or rather the middle, deck being two or three feet below the water. The effect of all this additional topweight in the vessel above the main deck may be expected to render the stability small, and calculations show that the margin of stability under such conditions becomes dangerously low. In the case of the vessel I have been describing, whose constructed load line was within 4 feet of the upper deck, the metacentric height was only 0.7 feet. In other words, if the cargo shifted sufficiently to incline her through even a moderate angle she would be in imminent danger of capsizing: thus scarcely creating surprise that such vessels have capsized, and that this has sometimes occurred a few days after leaving port.

Curves of stability of the different types of vessel referred to are shown on Fig. 6 (Plate III), together with an explanatory table of reference, and the curve marked **A**, shows the stability of one of the "three-deck" vessels referred to, loaded as I have described. It will be seen that it is exceedingly small and unsatisfactory. Curve C shows the effect which would be produced on this vessel by increasing the breadth two feet. The stability at moderate angles of heel is increased considerably by this step.

The effect which *depth of loading* has on the stability of the vessel is clearly seen by curve D, which shows that by increasing the freeboard one foot, and retaining the original breadth, a great gain in point of stability and safety is obtained even as compared with increasing the breadth 2 feet.

In this case, the maximum stability is increased from 25° to 40°, while the range of stability is extended from 52° to 80°.

From this it appears pretty evident that whilst the types of steamers have been gradually altering through the stages described from the flush-decked vessel of one deck and two tiers of beams, up to the vessel with two decks and three tiers of beams, or what is known as the "three-deck" vessel, in each stage the topweight being increased and facilities afforded for deeper loading—the necessary stability has not been made commensurate with the requirement for the latter type of vessel, and hence there are a large number of cargo-carrying steamers now in existence of this class, to which great care will have to be applied in loading, particularly the smaller ones, when they are conveying homogeneous cargoes, if the accidents with which we are acquainted are to be avoided.

The question, however, is not only how are we to deal with similar vessels in existence, but also how is the safety of this type of vessel to

be improved in building others? One of the most essential changes is to increase the beam. Another of not less importance is to provide a greater freeboard. And here it may be interesting to draw attention to other tendencies which have kept the relative beam of steamers small, in addition to the belief, as before stated, that a small midship-section was an important element as regards speed. Steamers when light are stiff, compared with sailing ships, and when in ballast are uneasy, and tend to strain themselves if the beam is too much increased. They also have frequently to take in heavy dead-weight cargoes, and without the special arrangements for the stowage of such cargoes ordinarily adopted being carried further than at present, broader vessels would labor heavily. Considerations of this kind have tended to keep cargo steamers narrow, and as they frequently carry heavy dead-weight cargoes on one voyage, followed by light cargoes the next, causing great differences in their stability, the design in most favor under such circumstances has been a compromise, in order to meet these various requirements.

The greater original cost, and the expenses in working steamers as compared with sailing vessels, have also made rapid dispatch in port a question of greater importance; the consequence of this has been that too little attention has been given to the stowage of cargoes of different specific gravity in steamers, and they have too often been supposed to be sufficiently safe, whether loaded with a cargo of iron ore on the ceiling, or filled with a cargo of grain.

No compromise, however, in form or proportions, will insure immunity against laxity of this kind, and unless in loading them those who are in command exercise more intelligence as to the question of stability, and are guided more by experience, as has been the case with sailing ships, similar accidents will recur, whatever provision may be made to prevent them.

In consequence of nearly all the steamers which have foundered this winter being fitted with double bottoms, it has been associated in the minds of many with the direct cause of these accidents, and viewed with disfavor by underwriters and others affected by these losses.

It should, however, be borne in mind that nearly *all* the cargo steamers now built are fitted with double bottoms, so that the fact of the vessels lost having double bottoms follows almost as a matter of course, and is no indication of the cause of the disasters.

That the double bottoms fitted to these vessels have, in consequence of insufficient beam, in some cases contributed to their loss there can be no doubt, but from the remarks one hears all round it is evident that much misapprehension exists as to the influence which these water-ballast tanks have on the capsizing of vessels of this type. It is supposed by many that, in addition to raising the cargo, the double bottom, being water-tight, has a lifting power inherent in itself to capsize the vessel. This, I need hardly say to the members of this institution, is

purely fallacious, as the stability of the vessel is not affected one iota whether the air in the double bottom is absolutely inclosed or in free communication with the atmosphere. These double bottoms are all fitted with air-pipes, and if the air itself had any tendency to rise or to lift the bottom of the ship it would rise through these pipes, but not being beyond atmospheric pressure it has no such tendency.

The real source of danger to the vessel in fitting these tanks, I need not say, is in lifting the center of gravity of a homogeneous cargo higher than it would be lifted by ordinary dunnage, and to this extent it renders a vessel more tender when loaded, and if her proportions and form make her otherwise a tender vessel, this influence might possibly render her dangerously unstable, and, without doubt, some of the recent losses may be attributed to this cause.

This fact in an exaggerated form has led some to suppose that the fitting of these water-ballast tanks in the bottoms of vessels is under *all* circumstances inconsistent with safety, but I need not say that no danger need be feared from this mode of construction, provided the proportions and form of steamers be made suitable to the height and extent of the tanks, and an intelligent judgment be exercised in loading them. The carrying of water ballast has become so essential a part of the economy of steamers, that it will well repay the time and consideration necessary to insure a combination of such a convenience with the safety to the vessel.

I have said that in cargo steamers it is necessary to effect a compromise between too little stability with grain and other homogeneous cargoes, and too much with dead weight, such as iron, &c.

I need not add that it is better to err on the side of the latter than of the former. One leads directly to unsafety, the other leads to uneasiness and straining, but only indirectly to danger; and this can be avoided, once it is understood, by lifting the dead-weight cargoes.

None of the information gleaned from the survivors, and from other experience with vessels loaded with iron in the lower hold, goes to indicate that any actual loss has occurred from the vessel having *excessive* stability.

But here again we must not go to extremes, for even recently cases have occurred where steamers have been placed in some jeopardy from excessive stability and violent rolling, owing to iron being stowed too low in the hold. Beyond the greater risk of the engines breaking down, and of shipping heavy seas, it would be wrong to ignore the wear and tear and straining action on the ship.

In passing, it may be interesting to notice the following example of a new steamer, which recently made extremely heavy weather, and which has been attributed to the heavy dead-weight cargo of iron being stowed too low.

I have given in Fig. 6 an approximate curve of stability of this "three-deck" steamer, marked H, whose dimensions are 285 feet, by 35 feet 3

inches, by 24 feet 5 inches. This vessel recently sailed from this country to America with a cargo composed principally of iron. There were 1,700 tons of this stowed in the hold, extending up to within 2 feet of the middle deck, and 300 tons between decks, and the approximate metacentric height is computed to be, when so laden, not less than 3 feet 6 inches. On her voyage she encountered heavy weather, and the consequence was that the vessel was severely strained. On her arrival at the port of destination it was found, on examination, that many butts of outside plating and rivets were started, and the decks strained and leaking, besides other damage from the same cause. The difference between the curve of stability of this vessel, and that of the vessels loaded like those which have capsized, is very striking, and there is obviously room for abundant safety between them, free from any fear of excessive stability.

Experience thus gained, however, has led to improved loading on future voyages, by raising the height of similar cargoes and placing a greater portion of the iron on the middle deck. This, as before said, merely requires experience and judgment, and need not occasion additional outlay. Such experience has to be gained in loading *all sailing* ships, and there is no reason why similar knowledge should not be acquired and exercised by those who have charge of steamers.

The dangers from loading heavy dead-weight cargoes can, therefore, be met without difficulty, but the principal danger arises, as shown from the recent losses, in carrying homogeneous cargoes, such as grain or coals, whose specific gravity admits of the vessel being filled to the upper deck. The inner bottom in such cases, being a fixture, cannot be removed, as portable dunnage can in a sailing ship, so as to admit of the cargo being lowered and stowed on the ceiling, and the question arises, How can "three-deck" vessels, similar to those which have been lost, be adapted to carry such cargoes with a proper margin of stability and safety? With reference to those already built of these proportions the remedy will readily present itself, that if these sad accidents are to be prevented there must, when carrying such cargoes as grain or coals, be less cargo carried between decks, or more heavy dead-weight below, as the case may require.

That narrowness alone does not involve danger, if proper judgment be exercised in loading, may be shown by illustrating the case of a spar-decked steamer which was referred to by Mr. W. John in a valuable paper read by him before this institution in 1877. This vessel was 276 feet long, and only 30 feet broad, and having a depth of hold to the spar-deck of 24 feet. She has been employed up to the present time principally in the grain trade, and on one occasion became disabled by an accident to the rudder-chains, when so loaded, and was abandoned. But though the cargo shifted, and she was rolling about in a heavy sea for some days, in the Bay of Biscay, she did not capsize. In fact, the calculation of the stability of this vessel at that time showed that she

might have been inclined through an angle of 111°, before the point of vanishing stability was reached. The cause of this, however, was that the vessel was properly loaded, having regard to her proportions and consequent stability.

The hold was entirely filled with grain in bulk, and as much stowed between decks as experience showed she could safely carry without making her unduly tender.

The owners of this vessel are well aware that were she loaded quite full between decks, so that her main deck would be under water, as is the practice with most of the "three-deck" vessels of the same total depth, in the first gale she encountered when so loaded, she would inevitably capsize.

Hence it is not only a question of beam, but also one of depth of loading.

Returning to the question of the "three-deck" vessels having only a small margin of stability, for the purpose of seeing how this stability can usefully be increased with the least loss and inconvenience, let us assume the 'tween decks to have two transverse bulkheads, within which cargo is to be stowed, and suppose we thereby carry 80 tons less than at present, and suppose the tank in the after-hold to be of a size to contain an equal weight of water, or to be divided by a water-tight division, as is now frequently done, this after-tank could be run up with water, and by retaining the same load line, a marked improvement in her stability and safety would be effected, as shown by the curve B, the range of stability being extended from 52° to 75°.

Here we have the simple question of less profit on the 80 tons of coal or grain cargo, or a continuance of excessive risk, and from my knowledge of steamship owners, I am of opinion there is not one would hesitate which to adopt when the two courses are clearly pointed out.

In the case of vessels about to be built, if we consider the dimensions of vessels now engaged in the grain-carrying and similar trades, in connection with the results of these calculations which have been given, we shall have no difficulty in arriving at one or more sound conclusions, which I sincerely hope will be accepted, as it may tend to their increased safety. It may be said almost with certainty that many of these steamers combine in themselves many of the worst features which contribute to instability and consequent unsafety.

These are—

1st. Small relative breadth to both depth and length.

2d. Great fullness of form throughout below the water-line and extreme flatness of floor.

3d. Low freeboard.

4th. Undue height and extent of double bottom.

The remedies, as I before stated, are greater beam, a more shapely form, a greater freeboard, and a double bottom not deeper than necessary for the purposes of water ballast.

But notwithstanding that these suggestions may be adopted advantageously, and a more stable vessel be obtained, it still remains, if we keep to the present "three-deck" vessels, that we have a type of vessel intended in point of strength to be fully laden, but that when so laden having a very low freeboard, and therefore not the most suitable for encountering heavy seas.

And here the question arises whether the building of another type of vessel could not be encouraged which combines more elements of safety than the "well" ship or the "three-deck" vessel, and could perhaps be worked as economically.

Between the long poop and forecastle ship, having a high freeboard at each end, and a very low waist, and the full scantling "three-deck" ship, with short coverings over the ends and engine and boiler openings, with a low freeboard nearly all fore-and-aft, it may be asked, and often is asked, cannot a type of vessel be devised with a good freeboard all fore-and-aft that shall be an equally good paying and safer ship? It seems a question capable of easy answer, but in reality it is mixed up with many others that open up a vexed field of inquiry. It is often asked why in cargo steamers of the long poop type, where the poop and forecastle together cover perhaps two-thirds the length of the ship, the further obvious and inviting step is not taken of covering in the "*well*," and getting a good safe freeboard all fore-and-aft? The answer usually is that the prescribed draught of water of the vessel would not admit of cargo being carried in the new part, whereas the tonnage dues would be considerably increased. This question of tonnage measurement is indeed the great obstacle to improvement in the types of ships for the Atlantic trade, and especially the grain trade, as it handicaps both the awning-deck and the spar-deck type of ship, which naturally lend themselves to the maintenance of a good healthy freeboard and freedom from capsizing. I have given you an instance of one of these ships—a spar-deck vessel, which knocked about abandoned for days, nearly on her beam ends with grain cargo, shifted in heavy weather, and did not capsize. In fact, she could not capsize because only a small part of the cargo was between decks, and its total center of gravity was sufficiently low to give the vessel in a measure the righting properties of a lifeboat.

The objection to the type is that all this 'tween-deck space, which gives great safety to the ship, but earning no freight, has to pay tonnage dues, just as if the whole ship was filled right to the upper deck, and loaded two or three feet deeper.

Of course it may be said this tonnage question is an old one, and has been debated over and over again. This is quite true; but I think few believe it is yet satisfactorily settled, and it is to my mind so intimately mixed up with this great loss of life and property at sea that this must be my excuse for again raising it. Where a vessel is covered with a lighter superstructure, such as an awning deck, for purposes of safety,

and which cannot possibly be filled, or nearly filled, with cargo, unless the ship is allowed to be loaded below the main deck, I would ask why the space actually occupied by cargo should not be measured, as is now done by the recent merchant shipping act, with deck cargoes, instead of the whole space, or say a certain deduction made from the 'tween-deck space? No doubt there are difficulties in the way, but they are, to my mind, small compared to the great end that would be achieved, and I trust this institution will give it their most serious consideration, and press it on the attention of the proper authorities.

It is only those intimately associated with the Mercantile Marine who see how often, day by day, sometimes comparatively in small things, the tonnage laws tend to prejudice the safety of ships.

When, for instance, it was found that low and inefficient wood coamings to hatchways in cargo steamers contributed to their loss in several instances iron coamings came into existence; and as this material enabled the coamings to be made much higher without practical difficulty, a very beneficial change set in toward making them high, so as to reduce the chance of heavy seas forcing them in, or large bodies of water resting on them. This was discouraged by the space so inclosed being added to the tonnage measurement, and so adding to the working expenses of the ship.

The same may be said of the protection round the openings of the engine and boiler space. The best protection possible is an inclosed bridge-house around the engine and boiler openings; but as the law at present stands it encourages the ends of this bridge superstructure being left open, instead of being closed by iron bulkheads.

I was much struck with this a few months ago, when I officially visited a large number of steamers in course of construction in the North for the Atlantic trade, and on pointing out to the owners or builders the desirability of continuing the bridge-house to the sides of the vessel, and inclosing it so as to secure effectively the casings round the engine and boiler openings against heavy Atlantic waves, I was invariably met by the observation that it would add too much to the working expenses of the ship, as this space would be measured for tonnage.

Where builders and owners are willing to incur outlay in the first place to secure additional safety, it is rather too much to put a tax on them for this outlay forever after.

These are all parts of the great question whether the tonnage laws could not be so amended as to encourage safety and safe types of merchant ships, rather than as at present tending sometimes in the opposite direction.

We all know that those who administer the tonnage laws are as desirous as any of us to contribute to the safety of life and property, and it is toward the *amendment* of the law rather than to censure its administration that my remarks are directed.

I now come to a branch of the subject that has for months attracted considerable attention, and it is one of great importance. I refer to the losses of grain-laden ships during the present winter. It may be in the recollection of many of my hearers that a series of almost unparalleled disasters occurred during the winter of 1872, and led to much excitement. I cannot help believing that the great attention the subject received at the period mentioned led to greater care being exercised by those responsible for the loading of grain cargoes in the succeeding years, for the losses were immediately reduced, as will be seen by the appended table, giving the names and particulars of cargo steamers foundered and missing during the years 1872 to 1879 inclusive.

The losses of the present year have also produced considerable excitement, and show that this subject of grain cargoes still requires careful attention. This is a matter which unfortunately can only be controlled indirectly from this country, for the very simple reason that the vessels are loaded in foreign ports; and if, from insufficient attention to the stowage by those intrusted to supervise it, the vessel is lost on the voyage, neither the evidence nor the persons guilty of the negligence are forthcoming in this country for examination. The most we can hope to do at this institution is, I fear, to make the perils of improperly-stowed grain cargoes known as widely as possible, and to point out the best practical remedies known to those who have given particular attention to the subject. That the cure for wholesale disasters lies within practicable limits may, I think, be taken for granted, and it is borne out by the improvement effected immediately after the disasters of 1872.

Further striking evidence of the same kind may be obtained from experience of the grain trade of Montreal. No port on the American continent, it has been stated, suffered more from the loss of grain-laden ships than that port did previous to 1873; and it will be seen from the table of losses that within a period of four weeks, during the winter of 1872, no less than six steamers, grain-laden from Montreal, either foundered or were missing. At Montreal, it may be known to many, they have a port warden, invested with certain powers over the shipping loading in the port. Up to the date in question, 1873, a ship-master loading grain in the port was liable to a fine of $40 if he did not comply with the port warden's regulations.

This fine was so ridiculously low that ship-masters used to pay it as a matter of course, and load their ships as they liked, and numerous losses used to ensue.

In that year, however, the fine was raised to $800 for evading the port warden's regulations, and since that time *not a single grain-laden vessel* from the port of Montreal has foundered at sea.

These regulations, together with some unofficial ones, more or less enforced at the ports of New York, Philadelphia, Boston, and Balti-

more, all stipulate for the fitting of shifting-boards, and for carrying a portion of grain cargoes in bags.

We have shown that in the case of Montreal the measures now taken for enforcing the regulations are exceedingly stringent, and that they have been of late years exceedingly effective. The recent losses of grain-laden vessels we have to deplore have arisen among ships loaded at the United States and Black Sea ports, and the question naturally arises whether the rules for loading grain, set forth by the surveyors to the underwriters' association at these ports and hereto appended, are fairly enforced. It has been objected that Montreal is scarcely a typical port, because the Saint Lawrence being closed by ice during a portion of the winter, the average losses may be expected to be less. But this certainly did not prevent the great losses which occurred from this port previous to the regulations of 1873.

When recently in America, I had opportunities of observing the loading of grain in bulk by means of elevators, and the difficulty of properly filling the hold by such means is only too apparent. The continuous stream of grain which pours in produces a stifling dust to such an extent that it is beyond human endurance to remain in the vessel sufficiently long to properly trim it, so as to fill the hold in the wings under the stringer plates and similar places.

To show the serious nature of this, I may mention that during my visit there a steamer had left port so loaded, and after encountering heavy weather had to put into a neighboring port, when it was found the grain had settled to such an extent as to require over 1,200 bushels to fill the after-hold alone. Many opinions exist as to the settlement of cargoes of grain shipped in bulk during a stormy voyage, but there is no doubt it is greater than is generally supposed with the present dispatch of loading.

Another instance of this I may mention, in the case of a "three-deck" steamer recently arrived home from an American port, loaded with grain in the hold in bulk, sufficiently high to enable just two tiers of grain in bags to be stowed between the top of the bulk grain and the middle-deck beams. The depth of hold to the middle deck was 17 feet; and it was found that, on the removal of the hatches, though the grain had been stowed in bags on boards laid on the top of the bulk grain, these had settled so much in some places as 30 inches.

Somewhat similar instances may be given, where the grain had been stowed in bulk to a height of a foot or more above the hold-beams, with bags on top stowed on boards and extending up to the deck, and, the vessel having put back, it was found that the bulk grain had settled below the beams and shifted, leaving the bags and boards resting on the beams.

The foregoing are sufficient to show that, as at present loaded at some ports, the grain in many of the vessels settles down to a considerable extent, thus rendering it impossible to keep the compartments full.

It must be evident that, with such experience as this, shifting boards fitted only 3 or 4 feet deep below the beams, as is often the case, are next to useless to prevent displacement of the cargo.

It is well known that all grain will settle somewhat on a long voyage, even when it has been carefully trimmed into the wings and under the beams and stringers. Some description of grain of course more than others. The large amount of settling down in grain cargoes which has recently been heard of, however, must be due in great measure, as I have indicated, to the haste with which the grain is run into the vessel's hold from the elevators, and which does not admit of its being properly trimmed under the beams and stringer plates. I have heard of steamers of from 1,200 to 1,800 tons laden in some of the American ports within ten hours, and where this is the case it is obviously impossible to attend to the trimming.

If we glance briefly at the conditions of grain loading, they will be seen to be somewhat as follows:

1. The simplest is, that of vessels having only one deck, with or without hold-beams, and carrying grain of such a kind that her holds can be filled without the vessel being overladen. Here, it appears easy enough to fill the hold with bulk grain, as has been customary from the Baltic and Black Sea ports; and this mode, with proper shifting boards, might not be unsafe, provided the grain be properly trimmed into the wings, and trodden down so as to obviate any danger of its settling materially during the voyage. In fact, this practice has been adopted for years, and when adequate care has been taken it has been done successfully. Or, still better, the hold may be filled up to within a few feet of the deck with bulk grain, then properly trimmed and leveled and covered with boards, the remaining space up to the deck being filled in tightly with grain in bags. Shifting boards should, of course, be fitted as in the previous case, and it is of great importance that these should be sufficiently strong, and extend well down into the hold—in my opinion, to the keelson.

2. The step from this is, when the same ship has to carry a cargo of grain too heavy in its nature to enable the holds being completely filled without being overladen. This, perhaps, occurs oftener in sailing ships than in steamers, but the principle to be borne in mind in both is the same—viz, that in whatever part of the ship grain is loaded, the cargo should reach to the deck. To carry this out, it is necessary to bulkhead off the part of the hold that is not to be utilized so that the remainder can be properly filled up. This has to be done with due regard to the trim of the ship and her depth of loading, but is often not sufficiently considered. If too large a space is left for cargo, it may become a choice of two evils, as the vessel fills up, either of the vessel being overladen, or the holds not being properly filled. Again, it has not unfrequently happened that these temporary bulkheads have given way through the pressure of grain as the vessel pitches at sea, when of course the sur-

face would become free, and shifting would take place. When adequate precautions are taken against these contingencies this case resembles No. 1, and I need not further dwell upon it.

3. The next typical case is that of a vessel having two complete decks laid, carrying grain of such a nature that her holds can be completely filled, and also between decks, to the upper deck, without being overladen. This, I may state at once, is one of the most difficult and troublesome of all to deal with, as you will immediately see. The lower hold resembles the hold of the one-decked vessel, but with this difference: In the latter if, after all precautions have been taken, it is found the ship has got a list at sea, the hatches can be opened, if the weather moderates, and the grain can be retrimmed before it has gone too far, or it can be filled up from bags carried for this purpose.

In the former case, however, all access to the cargo in the lower hold is cut off by the cargo in the 'tween decks, and a slight list may go on increasing until it becomes serious, unless the lower hold is well secured against such a contingency. Again, the cargo in the 'tween decks itself may be capable of shifting, and thus the danger is two-fold in this type of ship, as compared with a vessel having only one deck laid.

Many devices have been resorted to in these vessels for securing their safety, but they may be ranged generally under two heads, based on two different principles.

One is to make the stowage of the lower hold complete and distinct in itself, securing the bulk grain by means of boards and bags on top of same, and with shifting boards extending, in some cases down to the keelson, and carrying the remainder of the cargo between decks in bags. The other principle is to provide feeders to the lower hold from the 'tween decks, so that, in the event of the grain settling below, loose grain will run down to fill up the empty spaces.

It can scarcely be said of either of these principles that it is unsound, but much depends upon the way in which they are carried out. This is especially so in the latter case, for it is difficult with a deck laid to make the arrangements for feeding from the 'tween decks sufficiently perfect. This is especially so where the lower deck is of iron. Where it is of wood it is common for a few strakes of deck on each side near the stringer to be lifted, and these, together with the hatchways, fulfil, to some extent, the object of filling up the empty spaces in the lower hold caused by grain settling.

Where the deck is of iron, a series of small hatches are sometimes cut at the side for the same purpose, although frequently the communication is by no means sufficient to insure the lower hold being efficiently fed from between decks. Another important point to be borne in mind in reference to this mode of stowing grain cargoes is, that by feeding the lower hold from the 'tween-decks the risk of the 'tween-deck cargo shifting is increased.

Sometimes the 'tween decks is filled with a combination of bulk

and bag grain, the bags being piled round the hatches and feeders, where loose grain is stowed in bulk. This has often been adopted with safety, but it is by no means perfect. It is not certain that the grain under the middle-line hatches could find its way into the wings, and I have heard of instances which indicate that it does not always do so in cases of grain shifting; and although the same doubt does not apply so distinctly to feeders in the wings, they have another important drawback not generally noticed. In the case of the grain below deck shifting, and an empty space being left on one side, it will be clear that the feeders on that side might be called into play, and be emptied into the lower hold while the other side remained full. This, however, would obviously not cure the list of the ship, and is therefore not sufficient.

In some cases trunks have been led down from the upper deck to the lower hold, so that grain could be poured down from bags to fill up the empty space, in the event of the grain settling or shifting.

4. The other typical case is that where the lower hold is filled with grain, but a portion only of the 'tween decks is filled, as in the case with spar-decked vessels, and sometimes with "three-deck" ships. In this case temporary bulkheads have to be fitted between decks to contain the latter, and the lower hold has to be made secure against shifting, as in the previous case. I have indicated in Fig. 6 that spar-decked steamers so loaded with the main deck out of water, may have great elements of safety, in consequence of their much greater freeboard, as compared with "three-deck" ships of similar size, loaded as is customary; and it may be remarked that in the recent losses, not one of this type of vessel is to be found in the table setting forth the particulars of these losses. Hence the desirability, which I must repeat, of encouragement being given to such a type of vessel, with which this mode of loading is necessarily connected.

In the foregoing rapid sketch of the conditions of grain loading, I have necessarily been compelled to confine myself chiefly to the principles involved, and have had to omit many variations in detail, and devices resorted to under the different conditions of loading which exist. I cannot, however, pass from this question of grain-loading without a word on the proposal to carry all grain in bags. This is a question that is now receiving investigation by a select committee of the House of Commons, who will, I doubt not, arrive at a sound conclusion on the subject. That it would be more expensive there cannot be a doubt, and my inquiries have led me to the conclusion that this would amount in an American voyage to about $8\frac{3}{4}d.$ per quarter, or say £360 per voyage in a vessel of about 1,200 tons net register, including the cost due to delay in loading. That a cargo, composed partly of bulk and partly of bag grain, can be made as safe as a cargo containing all bags, is a question on which all practical men are agreed, and I think I have shown that behind the losses which have occurred there lie dangers from deficient stability, and other causes, which would not be cured by

carrying all grain in bags, and my endeavor has been, so far as I have been able, to shadow forth the relative magnitude of the different sources of peril.

In fact, the figures themselves in the table of losses show that there were as many coal-laden steamers as grain-laden steamers lost during the months of the past winter; and although it is possible for coal to shift similarly to grain, it is not a cargo which is prone to shift, or which would be considered dangerous in a fairly-designed vessel. In view of these facts there is nothing to show that the inherent deficiency of stability of the vessels, loaded as they were, might not have been as active an agent, if not a more active agent, in creating the disasters we deplore, as the shifting of the cargo.

One other cause of danger, which I mentioned in the early part of this paper, remains, viz, overloading, and I need not dwell upon it, for my views on that subject have been laid before this institution at great length on previous occasions. That it is a serious source of peril will be evident from the calculations and diagrams I have laid before you, while it is a subject surrounded by enormous difficulties every one will admit who has attempted to deal with it; but it is hoped that, by attention being drawn to the subject in a manner to show the magnitude of the evils which result from it, this source of danger, which is getting less, will soon altogether disappear.

In conclusion, I have only to apologize for occupying so much of your time, but my excuse must be the interest now attached to the subject and its great extent, and my strong conviction that, unless reviewed broadly and somewhat comprehensively, misapprehensions might arise, instead of the paper leading, as I hope it will, to a full discussion of the subject, which at the present time has become a matter of public importance.

[American rules referred to in the foregoing paper.]

Rules to be observed by vessels loading grain and also grain and general cargoes, in the ports of New York, Baltimore, Philadelphia, and Boston, under the inspection of the undersigned.

LOADING ALL BULK, OR PART BULK AND PART BAGS, AND ALL BAGS.

1. Vessels being loaded with grain in bulk or bags, both or either, must have a pump-well sufficiently large to admit of the passage of a man to the bottom of the well and room to work conveniently when there; say about 4 feet fore-and-aft and athwart-ships, and access thereto must at all times be had, either by a man-hole through the upper deck, or by a clear passageway between decks from the after hatch. If necessary, the pump-well must be either cased or matted.

2. The floor must be laid on sleepers of scantling 2½ by 4 inches in size, 16 inches apart, supported by studs of a corresponding size, also 16 inches apart. It must be raised at least 12 inches from the floor of the vessel, in the bilge 15 inches, and in vessels that are very flat or sharp, increased or diminished at the discretion of the inspector. In no case must the floor be laid on the bilge keelson, notwithstanding

the keelson may be more than 12 inches high, but there must always be sufficient room for a watercourse under it. The floor is considered as extending from the keelson to the side of the vessel, and not terminating at the bilge keelson. It must be laid with two thicknesses of 1-inch boards, and care must be taken that it be perfectly tight, and joints broken; the boards should be of equal width.

3. The air streaks must be covered and made grain-tight, and all lodging knees, bosom knees, and open seams must also be cleated grain-tight. Between-deck scuppers must be closed.

4. Single-deck vessels, or vessels with one deck and beams, must have forward and after bulkheads, and two trimming bulkheads if required, the uprights to be run down to the floor and secured; in loading, the middle compartment should be filled first, and the end ones left to trim the vessel. Double-decked vessels will require bulkheads between decks to shut off cargo, if loading too deep.

5. The studs for the forward and after bulkheads, for vessels not exceeding 14 feet, must be of spruce or pine 3 by 6 inches in size, and of one entire piece; for vessels of a greater depth than 14 feet they must be 4 by 8 inches, or in that proportion; they also must be set 22 inches apart from center to center, firmly secured at the top and bottom, and properly braced and cleated on the ceiling of the vessel, to resist the pressure of the grain. The forward bulkhead will require extra security.

6. The sides of the vessel above the turn of the bilge must be ceiled, after the manner of clapboarding, properly furred from the sides of the vessel, and cleated grain-tight.

7. Shifting planks 2 inches thick, or two thicknesses of 1-inch boards, must extend from the deck on each side of the stanchions, running down to the keelson between fore and mizen masts; fore and after hold, at the discretion of the inspector, fitted tight under the deck, and beams and carlins on one side; stanchions to be shored from the sides of the vessel if not properly secured. Masts to be cased, unless running through cabin or deck house.

8. Water-tanks, either of wood or iron, must be properly cased to prevent damage.

9. Vessels having shifting planks properly let in of sufficient thickness for Black Sea trade will require the balance of the shifting boards double, as in Rule No. 7, running above the planks several inches, and a shutter put in on one side; also shifting boards must be put in the hatches as high as possible, to keep the grain from running over from side to side under the hatches, when closed at sea.

10. Materials for ceiling must be perfectly dry, and all unsound knots must be covered.

11. Care must be taken that the grain is well trimmed up between the beams to the deck, and the hatches completely filled.

12. Vessels under 300 tons, American register, may have the floor and shifting boards clapboarded, the lap to be not less than one inch, and the stanchions not more than 7 feet apart.

13. Grain in bags, when stowed on bulk or loose grain, must have boards or sails under it to prevent the bags from settling into the bulk grain.

14. Double-decked vessels are required to leave off the between-deck hatches, and to take up a plank, if necessary, in the wings between fore and main masts, so as to allow the cargo to settle into the lower hold, to secure stability.

15. All iron vessels will be required to follow the foregoing rules, except as to ceiling the sides.

LOADING ALL BAGS.

1. Vessels being loaded with grain in bags, or any part of her cargo with grain in bags, must observe the same rules as to casing pumps, and must be dunnaged on the floor and on the bilge to the same height as for bulk grain, and 2½ to 3 inches on the sides up to the beams. The cargo between decks must be properly dunnaged from the sides and deck when necessary.

2. The dunnage in the hold must be laid close from the turn of the bilge to keelson, and covered with sails or approved maps, covering keelson and running up nearly to the deck, so as to prevent any of the loose grain from running down into the floor of the vessel, and thence to the limbers and pump-well. If sails are used, they must be of good quality.

3. Shifting planks 2 inches thick, or two thicknesses of 1-inch boards, extending 4 feet from the beams downward, 4 to 6 inches apart, must be properly secured on each side of the stanchions in the hold and between decks, to prevent the cargo from shifting; and care must be taken that the stanchions are well secured.

4. Care must be taken that the bags are in perfect order, and that the seams of the bags are inside when stowed against the sides of the vessel, so as o keep any loose grain from falling down the sides of the vessel.

GENERAL CONDITIONS.

1. The draught of water to be regulated by 3 inches clear side for every foot depth of hold, or at the discretion of the inspector, measuring from the crown of the deck, at the lowest part of the sheer, to the water's edge amidships, when upright. A proper allowance will be made for iron vessels.

2. All vessels intending to load grain must give early notice when ready for ceiling, as also when ready for receiving grain.

3. Vessels having an additional deck put on after construction, or having a light upper deck, the depth of hold to be measured for draught from original or main deck.

4. Vessels complying strictly with the above rules, and loaded under this inspection will be entitled to a certificate to that effect.

5. Application for inspection must be made in writing, and a fee of ten dollars will be charged for such inspection and certificate.

6. Captains of vessels loading grain are requested to see if the decks of their vessels are in good condition before receiving cargo.

H. S. VINING, *Inspector.*

The foregoing is approved by New York and foreign underwriters.

NOVEMBER 28, 1877.

OFFICE OF THE BOARD OF UNDERWRITERS,
51 *Wall street, New York, October*, 1860.

TO OWNERS, MASTERS, AND AGENTS OF VESSELS.

Vessels (insured in offices of this board) loading grain in bags or bulk, on voyages from Atlantic ports of the United States to ports in Europe, will be required to conform to the following rules, to enable the surveyor to issue the proper certificate.

1st. The pump-well must be sufficiently large to admit of the passage of a man to the bottom of the hold, and room to work conveniently when there, say not less than 4 feet fore-and-aft, and 5 feet athwart-ship (reference, however, must be had to the size of the keelson and assistant-keelsons), and must be cased from the bottom of the vessel to the lower deck-beams.

2d. Access to the pump-well must be had either by a man-hole through the upper deck, or by a clear passage-way between decks from the after hatch. In no case must it be from the main hatch.

3d. Vessels being loaded with grain in bags must be dunnaged 12 inches on the floor, 15 inches on the bilge, and 4 inches on the sides up to the beams. If the vessel be very flat, the dunnage in the bilge must be increased at the discretion of the surveyor. In between decks must be dunnaged 3 inches from the sides and 2 inches from

the deck, and the dunnage laid athwart-ships, so that the water can run to the scuppers.

4th. The dunnage in the hold must be entirely covered with sails or boards, so as to prevent any of the loose grain from running down on to the floor of the vessel, and thence to the pump-well. If sails are used, they must be of good quality, and free from holes. When boards are used, care must be taken that they have a firm and equal bearing on the dunnage, and that the edges and ends overlap, so that the object above designated may be secured.

5th. Two inch shifting planks, extending 4 feet from the beams downward, must be properly secured on each side of the stanchions in the hold, and between decks, to prevent the cargo from shifting, and care must be taken that the stanchions are well fastened at the top and bottom. In no case must single boards be substituted for planks.

6th. Care must be taken that the bags which are stowed in the ground tier, as well as those that are next to the sides of the vessel, are in perfect order, and that the tiers are laid close and well filled. When stowed on bulk or loose grain, must have boards or sails under them, to prevent the bags from settling into the bulk grain.

7th. Bulk or loose grain must be taken in bins prepared for that purpose. Materials for bins must be of perfectly seasoned stock; unseasoned lumber must not be used where it will come in contact with the grain.

8th. Rules 1 and 2 likewise apply to vessels being loaded with *grain in bulk.*

9th. The floor of the bin must be laid on sleepers of scantlings 2½ by 4 inches in size, 16 inches apart from center to center, supported by studs of a corresponding size, also 16 inches from center to center. It must be raised at least 12 inches from the floor of the vessel, in the bilge 15 inches, and in vessels that are very flat or sharp increased or diminished at the discretion of the surveyor. In no case must the floor of the bin be laid on loose dunnage, nor must it be laid on the bilge keelson, notwithstanding the keelson may be more than 12 inches high; but there must always be sufficient room for a water-course under it. The floor is considered as extending from the keelson to the side of the vessel, and not terminating at the bilge keelson. It must be laid with two thicknesses of boards, so that they will break joints at the edges and ends; and care must be taken that it be perfectly tight.

10th. The studs for the forward and after bulkheads for vessels not exceeding 14 feet depth of hold must be 4 by 6 inches in size and of one entire piece; for vessels of a greater depth than 14 feet they must be 4 by 8 inches. They must be set 20 inches apart from center to center, firmly secured at the top and bottom, and properly braced and cleated on the ceiling to resist the pressure of the grain.

11th. The sides of the vessel above the turn of the bilge must be ceiled after the manner of clap-boarding reversed, and properly furred, so as to turn water from the grain; and all lodging knees, bosom knees, and open seams must be made grain-tight.

12th. Shifting planks 2 inches thick must extend from the keelson to the deck on each side of the stanchions, fitted tight under and between the beams and carlines, and care must be taken that the stanchions are well secured at both ends, and not more than 7 feet apart.

13th. Masts and water-tanks, either of wood or iron, must be properly cased to prevent damage from leakage.

14th. Vessels being loaded with over 12,000 bushels of grain in bulk, must have one intermediate partition or bulkhead, so that no bin shall contain over 12,000 bushels. Vessels loading grain in bulk in quantity exceeding one-half their registered tonnage or in bins exceeding 12,000 bushels each, on voyages from Atlantic ports of the United States to ports in Europe, will be required to conform to the foregoing and also to the following rules:

15th. Vessels with one deck, or one deck and beams, must have, in addition to the forward and after bulkheads, two trimming bulkheads (thus making a division of three compartments), extending ¾ down from the upper deck, except in cases where

the between decks are laid forward and aft, when they shall extend only to the lower deck, and so placed that, in loading, the middle compartment will be entirely filled, and the end ones left to trim the vessel. In the end compartments, if not entirely filled, the grain must be covered by bags of grain, or else with sails or boards, and secured by stanchions or covered with weight. The studs for the trimming bulkhead must be not less than 3 by 6 inches, and set 22 inches from the centers, of one entire piece, extending the depth of the vessel, and all studs must be firmly secured at the top and bottom, and properly braced and cleated on the ceiling.

16th. Vessels with two decks must have a midship bulkhead in the lower hold, and trimming bulkheads between decks, and two strakes of 'tween deck plank should be open fore-and-aft on each side.

17th. Stevedores must see that the grain is well trimmed up between the beams, and the space between the beams completely filled. *The draught of water to be regulated by the surveyor.*

18th. Owners and masters are particularly requested to inform the surveyor, at this office, of any vessel they may intend to load with grain, and any deviation required under peculiar circumstances must receive the approval of the surveyor.

Vessels loaded in conformity with the above rules may have a certificate to that effect from the surveyors appointed by the board of underwriters, and the respective insurance companies composing said board will be duly notified thereof.

CHARLES DENNIS, *Secretary.*

Amended, October, 1876.

TABLE OF

Cargo steamers foundered, capsized, or missing

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.		Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.	Decks.	Tiers.	
		Feet.	*Feet.*	*Feet.*					
George Cairns	1,146	225.0	31.3	17.9	7.1	.57	1	2	Part double bottom.
James Marychurch	905	209.5	28.3	17.9	7.4	.63	1	2	....do .....
Shannon	1,210	240.0	32.6	17.8	7.3	.54	1	2	....do .....
Gravina	950	230.0	27.6	17.9	8.3	.65	1	2	.....
Commander	1,160	240.0	30.1	21.8	8.0	.72	1	2	Part double bottom.
Devon	1,411	260.5	33.6	23.1	7.9	.70	2	3	.....
Charente	402	165.4	23.7	12.6	7.0	.53	1		.....
Cresswell	1,147	216.0	30.8	17.1	7.0	.55	1	2	.....
Jane Bingham	222	131.2	21.0	10.5	6.2	.50	1		.....
Scanderia	1,983	328.6	35.3	25.1	9.3	.71	2	3	.....
Dalmatian	2,065	335.0	34.2	24.0	9.8	.70	2	3	.....
Counsellor	809	216.2	28.2	17.3	7.6	.61	1	2	Part double bottom.
Chillingham Castle	1,613	271.5	32.8	24.1	8.2	.73	2	3	....do .....
Carolina	1,174	243.8	31.8	19.4	7.6	.61	1	2	.....
Otterburn	1,284	238.2	32.1	24.6	7.4	.76	2	3	Part double bottom.
Marc Antony	1,338	235.6	32.0	23.6	7.3	.73	2	3	....do .....
Florence	1,020	225.0	29.8	16.9	7.5	.57	2		....do .....
Marcus	726	221.3	24.2	14.9	9.1	.61	1		.....
Annie Broughton	1,229	229.3	32.4	17.4	7.0	.54	1	2	Part double bottom.
E. S. Judkins	889	205.4	28.3	17.9	7.2	.63	1	2	....do .....
Sphinx	849	213.0	29.0	17.3	7.3	.60	1	2	....do .....
Francisco Calderon	1,260	225.5	34.0	22.2	6.6	.65	2		.....
Jorge	1,791	282.1 Spar	31.2 deck.	17.6 26.0	9.0	.56 .83	2*		.....
Reindeer	1,025	219.7	29.1	17.1	7.5	.58	1	2	Part double bottom.

*And spar deck.

LOSSES.

during the winters of 1872–'73 *to* 1879–'80, *inclusive.*

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1872–'73.		
Montreal	Limerick	Maize	Oct. 6	Foundered off Sydney, C. B.	Capsized.
Montreal	Queenstown	do	Oct. 27 since	Missing	
Montreal	London	Wheat	Nov. 13 since	do	
Montreal	Dublin	do	Nov. 8	Foundered	
Montreal	United Kingdom	Corn	Nov. 5 since	Missing	
Montreal	United Kingdom	Wheat	Nov. 14 since	do	
Hull	Dunkirk	General	Dec. 12	do	
Berdianshi and Falmouth.	Cork	Wheat	Nov. 22	do	
Dublin	St. Nazaire	Coal	Sept. 27	Foundered	
New York	Queenstown	Grain	Oct. 8	Missing	
Liverpool	Palmero	General	Nov. 26	do	
Nicolaieff	Falmouth	Grain	Nov. 26	do	
Newcastle	Odessa	Coal	Nov. 20 since	do	
Baltimore	Queenstown	Corn	Nov. 14	Abandoned	
Shields	Odessa	Coal	Dec. 15	do	
Bona	Sunderland	Iron ore	Sept. 4	Foundered	
Civita Vecchia	United Kingdom	Patent fuel	Dec. 10	Abandoned	
Ibrail	Yarmouth	Barley	Nov. 20	do	
Nicolaieff	Leith	Wheat	Dec. 11	do	
Sulina	Falmouth	Barley	Nov. 17	Missing	
Kustendje	London	Grain	Dec. 4	do	
Outward	bound.			Foundered	
Homeward	bound.			Missing	
Homeward	bound.		Dec. 14	Capsized near Santellaria.	

Cargo steamers foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.		Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.			
1873–'74.		*Feet.*	*Feet.*	*Feet.*			*D'ks.*	*T'rs.*	
Macedon	410	176.9	22.7	13.5	7.8	.59	1	1	
Pallion	1,146	229.0	30.6	16.1 / 23.2	7.4	.76	2	3	Part double bottom
Perseverance	491	189.4	25.8	13.6	7.3	.53	1	1	
Amberes	250	152.0	20.3	10.4	7.5	.51	1	1	
Ormesby	1,480	250.1	32.1	21.1	7.8	.66	1	2	Part double bottom
Cambridge	1,255	243.5	31.8	17.0	7.6	.53	1	2	
Ismailia	1,629	300.5	33.3	22.6	9.0	.66	2		
Ardent	960	210.0	29.1	16.6	7.2	.57	1	2	Part double bottom
St. Helen's	806	209.5	29.1	16.6	7.2	.57	1	2	
Celerity	974	220.5	29.3	15.8	7.5	.54	1	2	Part double bottom
Woolsington	304	139.5	20.9	12.0	6.6	.57	1	1	
Sidra	1,422	260.0	31.2	23.4	8.3	.75	2	3	
Rhone	1,387	257.2	34.6	22.0	7.4	.63	2		
Anna	1,545	260.0	33.3	24.4	7.8	.73	2	3	Part double bottom
1874–'75.									
Despatch	944	221.4	28.9	15.3	7.6	.53	1	2	Part double bottom
Emma David	1,783	274.9	33.5	24.5	8.2	.73	2	3	do
La Plata	1,218	249.6	30.5	21.9	8.2	.72	2	2	do
Violet	1,282	219.6	30.1	18.1 / 25.1	7.3	.60	2 awng.	3 dk.	Part double bottom
Precursor	791	206.7	29.1	16.8	7.1	.58	1	2	
Alpha	1,292	259.6	31.8	18.0	8.2	.57	1	2	Part double bottom
Clifton	543	198.5	24.5	13.8	8.1	.56	1	1	
Russell	909	222.2	29.9	16.7	7.4	.56	1	2	Part double bottom
Cortes	1,518	260.8	32.0	23.9	8.1	.75	2	3	do

winters of 1872-'73 *to* 1879-'80, *inclusive*—Continued.

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1873-'4.		
Berwick	Glasgow	Copper ore	Oct. 27	Foundered off Kinnaird's Head.	1 deck.
Cardiff	Suez	Coals	Nov. 5	Foundered off Lundy Island; broke shaft.	2 decks; flush decked.
Cronstadt	Antwerp and Havre.	Grain	Nov. 30	Foundered; cargo shifted.	1 deck.
		Flour	Dec. 10, previous to.	Foundered, Santander.	1 deck.
			1874.		
Penarth	Constantinople	Coal	Jan. 5	Foundered, Bay of Biscay.	2 decks.
Udewalla	London	Oats	Feb. 12	Foundered; shifted cargo; heavy weather.	1 deck.
			1873.		
New York	Clyde	Oilcake, cotton, &c.	Dec. 18	Missing	2 decks.
Taganrog	Constantinople	Rye	Dec. 26	do	1 deck.
			1874.		
Shields	London	Coals	Jan. 8	do	1 deck.
Riga	Stettin	Rye	Feb. 12	do	1 deck.
Middlesbro'	Christiania	Rails	Mar. 12	do	1 deck, and long raised quarter deck.
Shields	Port Said	Coals	Mar. 12	do	2 decks; flush decked.
Liverpool	Palermo	General	April 9	do	2 decks, and break deck.
New York	Rotterdam	Wheat	May 28	do	2 decks, and short break.
			1874-'75.		
Alexandria	Hull	Cotton seed	Nov. 6, about	Foundered 160 miles west of Alexandria.	1 deck, long poop and forecastle.
Kertch	Antwerp	Grain	Nov. 24, previous to.	Foundered 180 miles from Malta.	2 decks, 3 tiers of beams.
London	Rio Grande	Telegraph cable.	Nov. 29	Foundered off Ushant.	2 decks.
Nicolaieff	Bergen	Rye	Dec. 13	Foundered off south of Lizard.	1 deck and awning deck.
Marianople	Falmouth	Barley	Dec. 15	Foundered 40 miles west of Gozo.	1 deck and raised quarter.
Alexandria	Hull	Cotton seed	Dec. 13	Foundered, Bay of Biscay.	1 deck, poop and forecastle.
Phillipville	Dunkirk	Barley	Dec. 23	do	1 deck, poop and break.
Nicolaieff	Queenstown	Wheat	Dec. 26	Foundered off Finisterre.	1 deck, raised quarter deck, bridge and forecastle.
Cardiff	Aden	Coals and steam launch on deck.	Dec. 16	Foundered, Bay of Biscay.	2 decks, 3 tiers of beams.

Cargo steamers foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.		Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.			
1874–'75.		*Feet.*	*Feet.*	*Feet.*			*D'ks.*	*T'rs.*	
Hong Kong	1,881	290.4	35.3	25.4	8.2	.72	2	3	
The Princess	510	176.3	23.0	13.9	7.6	.60	1	1	
Stad Brugge	1,072	240.0	30.6	18.6	7.8	.60	1	2	
Viceroy	1,139	255.4	29.4	16.7	8.7	.57	1	2	
Kathleen Mary	1,268	230.2	32.1	24.0	7.2	.75	2		
Berar	1,033	231.2	30.0	17.5	7.7	.58	1	2	
Bride	1,341	234.4	31.5	{ 17.4 / 23.8 }	7.4	{ .55 / *.74 }	2	3	
Thornaby	1,474	250.0	32.0	21.1	7.8	.66	1	2	
George Batters	1,116	232.9	29.2	20.3	7.9	.70		2	
Alice	975	225.5	30.0	17.1	7.5	.57	1	2	Part double bottom
Bengalese	1,474	251.8	32.4	24.3	7.8	.75	2	3	do
1875–'76.									
Oder	694	200.0	27.5	15.0	7.3	.54	1	2	
Frascati	503	179.4	25.7	14.9	7.0	.58	1	1	
Linthorpe	568	180.8	26.1	15.0	6.9	.58	1	1	
Martin Wiener	792	210.8	28.1	17.3	7.5	.62	1	2	
Caromandel	1,979	280.5	35.0	25.5	8.0	.73	2	3	
Cavalier	190	130.0	21.1	10.8	6.1	.50	1	1	
John Sauber	878	208.5	27.5	16.6	7.5	.60	1	2	Part double bottom
St. Peter	753	200.0	27.2	16.2	7.3	.60	1.	2	do
1876–'77.									
Sylvia	1,090	220.0	30.0	19.3	7.3	.64	2 awng.dk.	3	
Basuto	1,034	220.0	30.4	15.6	7.2	.51	1	2	

*Spar deck.

winters of 1872–'73 *to* 1879–'80, *inclusive*—Continued.

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1875.		
London	Japan		Feb. 22	Foundered off Abdel Kuri.	2 decks, 3 tiers of beams.
Antwerp	London	Maize	March 3	Foundered at sea.	1 deck, raised quarter deck, bridge deck and forecastle.
			1874.		
Cronstadt	Hull	Linseed, &c.	Nov. 26	Missing	1 deck and poop.
Hull	Revel	General	Dec. 3	do	1 deck, poop, and forecastle (part awning deck).
			1875.		
Odessa	Limerick	Wheat	Jan. 28	do	2 decks; flush decked.
Odessa	Havre	Grain	Jan. 28	do	1 deck, raised quarter deck and forecastle.
Alexandria	Hull	Cotton seed	Jan. 28	do	1 deck and spar deck.
Cardiff	Bombay	Patent fuel	March 18	do	1 deck, and long raised quarter deck and forecastle.
Porthcawl	Gibraltar	Coal	March 18	do	2 decks; flush decked.
Cardiff	Constantinople	Coal	March 18	do	1 deck, raised quarter deck and forecastle.
Odessa	Malta for orders	Wheat	April 29	do	3 decks; flush decked.
			1875–'76.		
Hull	Gothenburg	General	Oct. 16	Foundered North Sea.	1 deck and poop.
			1876.		
Cardiff	Sables d'Olonne	Coals	Jan. 6	Foundered, near Penmarch.	1 deck; flush decked.
Huelva	London	Ore	Feb. 27	Foundered	1 deck, poop, and forecastle.
			Published.		
Tyne	Hamburg	Coal	Oct. 7	Missing	1 deck, and short raised quarter deck.
Bombay	Liverpool	Cotton, &c.	Oct. 28	do	2 decks, forecastle, and bridge deck.
Swansea	Nantes	Coal	Dec. 16	do	1 deck.
Sunderland	Hamburg	Coal	Dec. 23	do	1 deck, raised quarter deck, and forecastle.
Huelva	Amsterdam	Ore	Jan. 6	do	1 deck, raised quarter deck, and forecastle.
			1876–'77.		
Philadelphia	Havre	Oats	Oct. 14, previous to.	Foundered at sea.	1 deck and awning deck.
Cardiff	Marseilles		Oct. 11	Foundered off Corunna.	1 deck, long poop, and forecastle.

Cargo steamers foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.	Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.		
1876–'77.		*Feet.*	*Feet.*	*Feet.*			*D ks. T'rs.*	
Genoa	1,873	290.2	34.1	25.0	8.5	.74	2 3	Part double bottom' 120 feet.
The Prince	493	173.2	25.1	14.8	6.9	.59	1 2	..... do .....
Woodham	1,340	251.2	30.4	{ 15.5 / 22.7 }	8.2	{ .51 / .75 }	2 3 spr. d'k'.	.....
Dhoolia	2,660	330.8	38.1	25.3	8.7	.66	2 3	.....
Lady Derby	576	174.6	27.3	16.8	6.4	.61	1 2	.....
Alexandra	581	180.0	26.9	16.1	6.7	.60	1 2	.....
Agnes Wyllie	302	140.0	20.0	12.1	7.0	.60	1	.....
Ethel	811	203.4	30.2	16.1	6.7	.53	1 2	Double bottom, 97 feet.
Govan	525	173.7	25.1	13.7	6.9	.54	1	.....
Ionia	1,758	303.0	32.7	25.7	9.2	.78	2 3	.....
Zampa	1,683	280.0	33.3	24.6	8.4	.74	2 3	.....
Halley	1,362	241.0	32.7	23.0	7.3	.70	2	.....
Wells	1,102	234.0	31.4	16.2	7.4	.51	1 2	.....
Pardo	1,194	234.8	31.2	16.9	7.5	.54	1 2	Part double bottom...
Cerdic	1,423	258.0	31.9	21.5	8.0	.67	2 3	..... do .....
James Mason	871	220.0	31.2	15.1	7.0	.48	1 2	..... do .....
Colombo	2,555	331.1	36.7	27.1	9.0	.74	2 3	.....
1877–'78.								
Damietta	682	208.1	27.2	16.3	7.7	.60	1 2	.....
Knapton Hall	903	221.0	29.2	17.5	7.5	.60	1 2	Double bottom, 132 feet.
Kate	969	214.7	29.2	16.5	7.4	.57	1 2	Double bottom, 142 feet.
Margaret	700	203.0	28.6	16.3	7.1	.57	1 2	Part double bottom...
European	2,272	307.2	37.7	27.7	8.1	.73	2 3	.....
Danaë	1,157	230.0	30.3	18.2	7.6	.60	1 2 iron.	Part double bottom..

winters of 1872–'73 *to* 1879–'80, *inclusive*—Continued

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1876–'77		
Sulina	Queenstown	Maize	Nov. 12	Foundered off Cadiz.	2 decks, 3 tiers of beams; flush decked.
Middlesbro'	Grangemouth	Pig iron	Dec. 3	Foundered off Shields.	1 deck, raised quarter deck, and forecastle.
Odessa	Falmouth	Grain	Dec. 8	Foundered, bar of the Tagus.	1 deck, and spar decked.
Alexandria	Hull	Cotton seed	Dec. 26, previous to.	Foundered off Finisterre.	2 decks, poop, bridge deck, and forecastle.
			1877.		
Granton	Hartlepool	Ballast	Jan. 2	Foundered off Souter Point.	1 deck, and raised quarter deck.
Cadiz	Dublin, Liverpool, and Glasgow.	Wine	Jan. 3	Foundered off Clogher Head.	1 deck, and raised quarter deck.
Middlesbro'	Carn		Jan. 1	Foundered off Goodwin.	1 deck, raised quarter deck, and forecastle.
Bibao	Newport	Iron ore	Feb. 6	Foundered off Lundy.	1 deck, poop, and forecastle.
Ardrossan	Rochefort	Coal	Nov. 16	Missing	1 deck, long poop, and forecastle.
Shields	Alexandria	Coal	Nov. 30	do	2 decks, 3 tiers of beams.
Newcastle	Aden	Coal	Dec. 7	do	2 decks, 3 tiers of beams; flush decked.
Odessa	United Kingdom.	Wheat	Feb. 8	do	2 decks; flush decked.
Memel	Hull	Linseed	Feb. 8	do	1 deck, long poop, and forecastle.
Saigon	Hong Kong	Rice	Feb. 15	do	1 deck, long raised quarter deck, and forecastle.
Galatz	Falmouth	Barley	Feb. 15	do	2 decks, 3 tiers of beams.
Cardiff	Gibraltar	Coal	Feb. 22	do	1 deck, raised quarter deck, and forecastle.
Hull	New York	General	Feb. 22	do	2 deck, flushed deck, 3 tiers of beams.
			1877–'78.		
Danzig	Stockton	Wheat	Oct. 15	Foundered off Shields.	1 deck, and raised quarter deck, and bridge deck.
Newport	Genoa	Coal	Oct. 15	do	1 deck, raised quarter deck, and forecastle.
Barrow	Gothenburg		Nov. 11	do	1 deck, long poop, and forecastle.
Cardiff	Malta	Coal	Nov. 29, previous to.	do	1 deck, and raised quarter deck.
Cape of Good Hope.	Southampton	General	Dec. 5	Foundered off Ushant.	3 tiers of beams; flush decked.
Revel	London	Wheat	Dec. 25	Foundered off Horn Reach.	1 deck (iron), raised quarter deck, and bridge deck.

Cargo steamers, foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.	Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.		
1878.		*Feet.*	*Feet.*	*Feet.*			*D'ks. T'rs.*	
Albert and Edward	1,215	230.0	31.7	17.4	7.2	.55	1 2 iron.	Double bottom, 151 feet
Kin Shan	1,527	260.3	32.4	22.6	8.0	.70	2 3	Part double bottom
Mexican	1,315	238.2	32.2	23.9	7.4	.74	1 2	
Friesland	2,525	335.5	37.5	25.8	8.9	.69	2 3	
Alice	469	180.0	25.0	14.0	7.2	.56	1	
Rose	796	196.1	28.6	16.2	6.8	.57	1 2	Part double bottom
Stamfordham	1,483	255.2	33.2	22.9	7.6	.69	2 3 1 iron.	Double bottom, 126 feet.
Cromwell	748	215.6	28.8	15.9	7.5	.55	1 2	Part double bottom
Corinna	1,103	247.3	29.1	17.4	8.5	.60	1 2	Double bottom, 150 feet.
1878–'9.								
Yoxford	1,990	285.0	35.0	24.4	8.1	.70	2 3 1 iron.	Double bottom, 154 feet.
Orontes	701	187.1	27.4	17.0	6.8	.62	1 2	
Diana	527	183.2	23.9	13.6	7.6	.57	1 2	
Vendee	644	209.6	26.2	16.6	8.0	.63	2 3 1 iron.	Part double bottom
Armstrong	920	212.7	30.1	16.1	7.0	.53	1 2	Double bottom, 105 feet.
Richmond	1,109	221.5	30.7	21.4	7.2	.70	2 3 1 iron.	Part double bottom
Birma	1,832	270.3	34.1	24.5	7.9	.71	2 3 1 iron.	Double bottom, 114 feet.
Bayard	1,498	240.0	33.0	24.0	7.2	.72	2 3 iron.	Double bottom, 74 feet.
Hellespont	1,330	250.5	32.9	22.7	7.6	.69	2	
Norman	911	215.0	30.0	15.5	7.2	.52	1 2	Part double bottom
Aberfeldy	1,352	245.0	31.6	22.6	7.7	.71	2 3	do
Ralph Creyke	553	166.0	30.0	13.5	5.5	.45	1 iron.	Part double bottom, 73 feet.

winters of 1872-'73 *to* 1879-'80, *inclusive*—Continued.

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1878.		
Tyne	London		Jan. 5	Foundered	1 deck, raised quarter deck, bridge deck, and forecastle.
			1877.		
Cardiff	Tangier & Bombay.	Coal	Nov. 29	Missing	2 decks.
Port Royal	Liverpool	General	Dec. 20	do	1 deck, 2 tiers of beams.
Java	Rotterdam	Produce	Jan. 17	do	2 decks, 3 tiers of beams, poop, and forecastle.
W. Coast of Africa.	Liverpool	Produce	Jan. 24	do	1 deck, poop, and forecastle.
Antwerp	Revel	Iron	Jan. 31	do	1 deck.
			1878.		
Baltimore	Ipswich	Maize	Mar. 28	do	2 decks, 3 tiers of beams, raised quarter deck, and forecastle.
Middlesbro'	Pomaron	Pig iron	May 9	do	1 deck; flush decked.
Cardiff	Malta	Coal	May 16	do	1 deck, raised quarter deck, and forecastle.
			1878-'9.		
New York	Havre	Grain	Sept	Abandoned, cargo shifted.	2 decks, poop, and forecastle.
Liverpool	Copenhagen	General	Sept. 27	Foundered, North Sea.	1 deck and break deck.
Swansea	Havre		Oct. 7	Foundered off Portland.	1 deck, and poop.
Santander	Cardiff	Iron ore	Oct. 10	Foundered near Santander.	1 deck.
Shields	London	Coal	Nov. 22	Foundered	1 deck and raised quarter deck, and forecastle.
Cardiff	Malta	Coal	Nov. 24	Foundered off Vigo.	2 decks, 3 tiers of beams; flush decked.
			1879.		
Tarragona	Hamburg	General	Jan. 3, previous to.	Foundered off Tarifa.	2 decks, 3 tiers of beams, bridge deck and forecastle.
			1878.		
New Orleans	Rouen	Wheat	Dec. 10	Foundered at sea, cargo shifted.	2 decks, 3 tiers of beams, poop, and forecastle.
			1879.		
Cardiff	Port Said	Coals	Jan. 13, about	Foundered at sea.	2 decks; flush decked
St. Nazaire	Newport	Ballast	Jan. 13	Foundered off Guilrinec.	1 deck, raised quarter deck bridge, and forecastle.
Philadelphia	Ipswich	Maize		Foundered	2 decks, 3 tiers of beams; flush decked.
Cardiff	Dieppe	Coal	Feb. 20	Foundered off Hartland Point.	1 deck, raised quarter deck bridge, and forecastle.

Cargo steamers foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.		Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.			
1878–'79.		*Feet.*	*Feet.*	*Feet.*			*D'ks.*	*T'rs.*	
Marienbury	818	221.4	29.3	16.9	7.5	.57	1	2	
Denmore	328	155.8	21.3	11.4	7.3	.53	1	1	Double bottom, 52 feet.
Lindisfarne	994	219.1	30.2	19.5	7.2	.64	1	2	
Copia	1,529	255.2	33.2	23.1	7.6	.69	2	3 1 iron.	Double bottom, 126 feet.
Herman Ludwig	1,505	271.8	32.2	25.0	8.4	.78	2	3	
Surbiton	1,373	240.0	32.0	22.8	7.5	.71	2	3	Double bottom, 150 feet.
Homer	1,916	285.0	34.2	24.4	8.3	.71	2	3 1 iron.	
Albatross	1,030	241.0	29.1	14.4 / 21.9	8.2	.49 / .75	2	3 spar dkd.	
Zanzibar	2,245	301.0	36.3	25.3	8.3	.69	2	3 1 iron.	Double bottom, 177 feet.
Louise	1,060	219.5	30.1	18.3	7.3	.60	1	2	Part double bottom...
Jura	362	178.3	22.1	12.5	8.0	.56	1	2	
Bermuda	1,792	275.0	34.2	24.7	8.0	.72	2	3	Double bottom, 142 feet.
1879–'80.									
Alfonso	295	145.4	21.2	11.3	6.8	.53	1 iron.	1	Double bottom, 77 feet.
Heimdall	1,520	248.8	32.5	21.4	7.6	.66	1	2	
Gurtubay	879	210.5	30.3	15.2	6.9	.50	1	2	Part double bottom...
Castlewood	1,896	280.0	34.8	24.3	8.4	.69	2	3 1 iron.	Double bottom, 112 feet.
Tiara	1,840	282.4	33.3	24.2	8 5	.72	2	3	Part double bottom ..
Emblehope	1,944	302.3	34.2	25.8	8.8	.75	2	3	
Capella	1,829	279.3	33.2	23.8	8.4	.71	2	3	Double bottom.....
Roscommon	1,500	245.0	33.3	23.0	7.3	.69	2 iron.	3	Double bottom, 110 feet.
Sheldrake	517	180.0	25.6	13.2	7.0	.51	1	1	Part double bottom...
Lufra	1,366	235.4	32.0	17.8	7.3	.55	1	2	
Persévérant	633	181.5	28.6	15.3	6.3	.53	1	2	Part double bottom.

winters of 1872–'73 *to* 1879–'80, *inclusive*—Continued.

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1878–'79.		
Danzig	Antwerp	Wheat	March 17	Foundered in Slieve.	1 deck, raised quarter deck bridge, and forecastle.
Leith	Aberdeen	General	March 20, Published.	Foundered off May Island.	1 deck, and long raised quarter deck.
			1878.		
Riga	London	Oats	Nov. 28	Missing	1 deck and poop.
Barrow	Montreal	Rails	Nov. 28	....do	2 decks, 3 tiers of beams.
New York	Antwerp	General	Dec. 19	....do	2 decks, 3 tiers of beams.
New York	Rotterdam	Grain and provisions.	Feb.	....do	2 decks, 3 tiers of beams; flush decked.
			1879.		
Boston	Liverpool	General	March 6	....do	2 decks, 3 tiers of beams.
Grimsby	Alexandria	Coal	March 27	....do	2 decks, 3 tiers of beams; spar decked.
New York	Glasgow	General (grain and provisions).	March 27	....do	2 decks, 3 tiers of beams.
Newport	Passages	Coal	April 17	....do	1 deck, long raised quarter deck, and forecastle.
Humber	Smyrna	Coal and ship's stores.	April 24	....do	1 deck, and short poop.
New York	Bristol	Provisions and groceries.	June 12	....do	2 decks, 3 tiers of beams.
Aarhuus	Ipswich	Barley	Oct. 18	Foundered off Yarmouth.	1 deck, raised quarter deck, and forecastle.
Nicolaieff	Bremerhaven	Barley	Nov. 2	Foundered off Terschelling.	1 deck, poop, and forecastle.
Bilbao	New York	Ore	Oct. 31	Abandoned off Halifax.	1 deck, long raised quarter deck, and forecastle.
Cronstadt	Rotterdam	Rye, linseed	Nov. 16	Foundered off Landholmer.	2 decks, 3 tiers of beams, poop, and forecastle.
Alexandria	Hull	Cotton seed	Nov. 29	Foundered, Bay of Biscay.	2 decks, 3 tiers of beams, short forecastle.
Sulina	Antwerp	Grain	Nov. 29	.. do	2 decks, 3 tiers of beams.
Alexandria	Hull	Cotton seed	Dec. 4	Foundered off Corrubedo.	2 decks, bridge house and forecastle.
London	Havana	Coal	Nov. 19	Foundered SE. of St. Mary's Island.	2 decks, 3 tiers of beams, short forecastle.
Bilbao	Glasgow	Mineral	Dec. 11	Foundered Ray Straits.	1 deck, raised quarter deck, and forecastle.
Shields	Genoa	Coal	Nov. 30	Foundered, 46 N., 9 W.	1 deck, long poop, bridge deck, and forecastle.
Bayonne	Antwerp	General	Dec. 17	Foundered near Conquet.	1 deck, long raised quarter deck, and forecastle.

Cargo steamers foundered, capsized, or missing during the

Name.	Gross tonnage.	Dimensions.			Proportions.		Number of decks and tiers of beams.	Extent of double bottom.
		Length.	Breadth.	Depth.	Length to breadth.	Depth to breadth.		
1879–'80.		*Feet.*	*Feet.*	*Feet.*			*D'ks. T'rs.*	
Voluna	339	137.2	21.1	10.0	6.5	.47	1 and p't awn'g d'k	
Borussia	2,075	292.0	38.6	25.0	7.5	.64	2 3	
Bengore	767	211.3	28.2	15.9	7.4	.56	1 2	
Kensington	1,401	240.0	33.0	22.4	7.2	.67	2 3 1 iron.	Double bottom, 100 feet.
Joseph Pease	1,793	280.2	33.7	23.8	8.3	.70	2 3	Double bottom, 186 feet.
Telford	1,747	270.0	34.0	24.4	7.9	.72	2 3 1 iron.	Double bottom, 105 feet.
Llanedarne	1,048	220.5	30.2	18.4	7.3	.61	1 2	Double bottom, 133 feet.
Mino	705	195.0	26.7	16.0	7.3	.59	2	
Marlborough	2,309	301.0	36.0	25.0	8.3	.69	2 3 iron.	Double bottom, 168 feet.
Joseph Ferens	1,803	270.0	34.2	24.5	7.8	.71	2 3 1 iron.	Double bottom, 124 feet.
Prometheus	1,622	254.6	34.1	23.2	7.4	.68	2 3 1 iron.	Double bottom, 138 feet.
Harriet	504	199.4	25.1	14.7	7.9	.58	1 2	
Dalton	1,325	235.0	32.5	17.9	7.2	.55	1 2	Double bottom, 153 feet.

winters of 1872–'3 *to* 1879–'80, *inclusive*—Continued.

Voyage.		Description of cargo carried.	Date of loss.	Cause, &c., of loss.	Remarks.
From—	To—				
			1879–'80.		
Glasgow.....	Jamaica.....	General.....	Dec. 19.....	Foundered at sea.	1 deck, raised quarter deck, and forecastle, and part awning deck.
Liverpool....	Havana via Corunna.	Ballast.....	Dec. 2.....	Foundered 250 miles from Corunna.	2 decks, poop and forecastle.
Penarth.....	Gibraltar.....	Coal	Jan. 23.....	Foundered, Cape Finisterre.	1 deck, poop and forecastle.
Liverpool....	Havana.....	Coal	.....	Foundered at sea.	2 decks, 3 tiers of beams, short forecastle.
New York....	Marseilles.....	Grain.....	Jan. 1.....	Missing.....	2 decks, poop, bridge deck, and forecastle.
New York....	Antwerp.....	Maize.....	Jan. 1.....	....do	2 decks, break, and forecastle.
Nicolaieff....	Dunkirk.....	Linseed.....	Jan. 22.....	....do.....	1 deck, long raised quarter deck, and forecastle.
Liverpool.....	Las Palmas	Guano	Jan. 29.....	....do.....	2 decks, poop and forecastle.
Cardiff.....	Odessa.....	Coal	Feb. 5.....	....do.....	2 decks, 3 tiers of beams, poop, bridge deck, and forecastle.
Tyne.....	Lisbon.....	Coal	Feb. 5.....	....do.....	2 decks, 3 tiers of beams, break, and forecastle.
Cardiff.....	Genoa.....	Coal	Dec., '79.....	... do.....	2 decks, 3 tiers of beams, bridge deck and forecastle.
Tyne.....	Lisbon.....	Coal	Dec., '79.....	....do.....	1 deck, raised quarter deck, and forecastle.
Tyne.....	Lisbon.....	Coal	Dec., '79.....	....do.....	2 decks, 3 tiers of beams, poop, bridge deck, and forecastle.

The PRESIDENT. Gentlemen, I cannot feel any surprise at the applause which has marked the close of the very able and interesting paper which has been read to us by Mr. Martell, and it now becomes my duty to invite comments upon that paper. Looking to its great public interest—I may say its great national interest—I agree with Mr. Martell in expressing the hope that there will be a very full discussion on it.

Mr. CHARLES W. MERRIFIELD, F. R. S. (associate member of Council). My lord, as no gentleman seems prepared to rise immediately, I thought I might economize time if I were now to make the few observations which I propose to make. In the first place, I think that the meeting owes a deep debt of gratitude to Mr. Martell for having prepared the wise, temperate, and wide-ranging paper that he has been so good as to lay before us. If I do not also call it exhaustive, it is because it is impossible to exhaust such a subject in such a time; but it is just the paper that we might expect from a man of the author's wide experience, thorough knowledge, and great attention to the subject. I was very much struck with one paragraph, which, being a very short one, I will, with your permission, read to you again. It is at p. 11:

> No compromise, however, in form or proportions will insure immunity against laxity of this kind, and unless in loading them those who are in command exercise more intelligence as to the question of stability, and are guided more by experience, as has been the case with sailing ships, similar accidents will recur, whatever provision may be made to prevent them.

I think that this is a paragraph which calls our attention in the most important way to the necessity of studying more seriously the stability of the steamships that we build, than has hitherto been our practice. As Mr. Martell has rightly observed, it was impossible, if not in the construction, at any rate in the loading of a sailing ship, to escape thorough attention to the question of stability; because the enormous amount of it that was requisite for a sailing ship insured this being done. In the merchant steamers, on the contrary, no such absolute necessity existed, and I am afraid the question has in many cases dropped out of sight. We are now running with much smaller margins of stability than we did when we first passed from sailing vessels to steamships, and we do not spend sufficient money in the calculations that the draughtsman requires to make, in order to make safe those enormously valuable and important structures—important not only in respect of money, but also in respect of the lives which they place in jeopardy. I would venture to say a few words as to the reliance to be placed on the extreme limits of stability, but first I would say that I consider it important in the very highest degree that more money should be spent in the calculating draughtsman's office. It seems to me rather an absurd thing to build a steamship costing somewhere between £20,000 and £50,000, and to stint those calculations which are necessary to assure us how we ought to load her, in order that we may know how she is to

go and return safely. There are some houses—I think they are getting very rapidly fewer and fewer—in which the question of stability is not really gone into at all. I do not think that is a wise economy. I do not advocate that everybody who is intrusted in any way with a ship, from the captain and the stevedore on one side, to the owner on the other, should be crammed with all the mathematical details relating to metacenter and statical stability, but I think there is plenty of room for doing a little more. We must not go too fast in that matter. The probability is, that if you were to give an inexperienced man all the curves that indicate the different forces that come into play in his ship, he would probably misunderstand them, and capsize his ship by the very precautions which he took to prevent it.

With reference to the extreme limit of stability, I think we must be careful not to be guided too strictly by the calculations on that matter without giving them a very large margin. For instance, taking the curve A in Fig. 6, the inference from the curve is, that if you heel the ship to an angle of 50° she will still have a margin of stability, although a very small one. Now, that is an inference that would be practically altogether unsafe. The margin is so small that any accident connected with her position on the wave, with any little water she might have on her deck, or the slightest shift of cargo, would render her capsizing a matter of certainty. Not only that, but the mere pressure of the wind on her side, her mere position relatively to the wave, would exhaust that small margin. We should in all cases leave a pretty large margin of stability, and what we really have to do is to apply impactive force to that, and then we shall find that we have to discount our margin of stability very considerably. When we get near the extreme limit of stability there is this to be said about it, that in a very tender ship, and a ship of which the cargo has a liability to shift, these two causes react very strongly upon one another, and an amount of shifting that might be perfectly safe with an extremely stable ship becomes exceedingly unsafe and dangerous when we have a tender ship. These two causes react upon one another and enhance one another, continually adding to one another's force. That is especially the case in new ships constructed with a well in which the water may accumulate without sufficient means to carry it off with extreme rapidity, not only to clear the deck in the course of a few minutes, but it is even necessary in such cases to clear the deck in a few seconds, unless the ship is to go over; because there is no such shifting cargo as loose water, whether on the deck or in an undivided hold. My own opinion is, that the stability of every ship turned out should be gone into in some manner, either by fresh mathematical calculations where you have to deal with a new type of ship, or by careful adaptation, by means of the study of the different co-efficients, where you have to deal with old types where the type is well known and is only slightly departed from. The only other observation I have to make is with reference to the ton-

nage. Now there is no question, as has been justly observed by Mr. Martell, but that our tonnage laws are simply in a wretched condition, and I have generally observed that when a law of that kind gets into too bad a state, so as to be entirely out of gear with the requirements of the different services, it is apt to become from that cause alone a great source of danger. Mr. Martell, with his wide experience, knows how, in detail as well as in gross; but, speaking generally, that when a legal principle gets very much adrift, unknown and unsuspected sources of danger are always turning up, and I would certainly urge upon all those who have any influence in the matter to get our tonnage laws thoroughly revised. I recollect on the occasion of the last bill being brought before Parliament to amend our tonnage laws, the very fault that was found with the previous state of the law, namely, that it was possible for a merchant steamer to have no tonnage at all, was renewed in a different form under the new bill. That is not the kind of legislation we want. I think you will agree with me that we are all infinitely obliged to Mr. Martell for his paper, and that it will do both this institution and the country a great deal of good to have had it before us, and afterwards to have had it thoroughly discussed.

Mr. JOHN MAC FARLANE GRAY (member). My lord, I did not hear the beginning of the paper, because I came in the middle of it; but at paragraph 7, on p. 6, we read, "When we hear of the funnel and ventilators being washed away in some of our largest passenger steamers," and so on, referring to accidents which produce very rapidly the destruction of the vessel, it calls to my mind a question to which I paid a good deal of attention, but for a technical reason the result of my investigation into it was of no value to any one; I refer to the loss of the steamer *La Plata*. What I discovered about that was this, that a quantity of water had accumulated in one of the holds. The carpenter and the engineer were not on speaking terms. The carpenter found water in the hold, and he opened a sluice without telling the engineer, and the water went into the after-hold of the vessel, where the engine was—the engine compartment. It was very fine—I think the calculation I made was that something less than forty tons of water in that after-hold would go over the floor plates; the vessel was suddenly reported making water; the engineer did not know where it was coming from, and he thought the vessel had sprung a leak, when it was just that small quantity of water put in, and if they had shut the sluice probably the vessel would have been floating now, but in the confusion of the plates being disturbed one of the plates cut the pipe leading to the ashcock, which was an inch and a quarter pipe; the engineers were then busy packing up their Sunday clothes to go ashore in, and not one of them attended to the pipe, and that pipe by a calculation would run in water sufficient to produce the foundering of the vessel in the time she went down. The accident of letting the water into the after compartment put the vessel down by the stern, and then the plate cut the

pipe and that was not attended to. One of the sailors told me that he did send for a bit of wood; the piece of wood was brought—a thole-pin; it was too small and it did not fit. I asked him why he did not put his cap about it. He said, "Sir, I was not going to lose my cap."

Mr. JOHN SCOTT RUSSELL, F. R. S. (vice-president). My lord, I am sure we all highly appreciate the paper, coming as it does from a gentleman who knows practically so much about the question in hand, and I think we are all very grateful for it, and are bound therefore to give it the due discussion which he invites. There is, I think, almost only one point on which I differ from him. He is very partial to, and, I observe, tries to shelter, his old friend the double bottom from the accusations which have been brought against it. I continue, from considerable experience of ships with double bottoms, to be of opinion that a double bottom is a great source of danger. I continue to think, from all I see of it, that double bottom leads to rapid decay, number one; and, number two, that a double bottom has in many cases been the cause of the capsizing of ships; therefore, I venture to suggest, as one of the remedies for the evils mentioned—the very old remedy you will say—old certainly, but not yet carried out—of still greater subdivision into compartments than has yet practically been adopted. Now, there is one mode of making compartments, which affords an immediate safety against the shifting of cargo, which has not generally been adopted. I dare say there is some objection to it. It is because I see so many who thoroughly know that subject that I now venture to raise this question. Why do you object so strongly to a longitudinal central bulkhead in the middle of the hold of the ship? Why do you? I say why do you? Because there are sundry conveniences in having a longitudinal bulkhead in the center of the ship which do not belong to bulkheads in other parts of the ship longitudinally. I much prefer myself, and I have been in the habit of using to a very great extent in many ships, the two longitudinal bulkheads, leaving the central space undisturbed, and having the two wings kept separate; but for our present purpose, and very many practical purposes, especially in vessels of small size, there are great inconveniences. I say, then, what objection is there in any size of vessel to central longitudinal bulkheads? Well, I do not myself know any except a little paltry inconvenience that now and then the ship-owners might be asked to carry a great big engine of some kind or other, and then there would hardly be room enough to get this great big engine down into the holds if the hatch was split into two. Now, that is unanswerable. I cannot make any objection to that. But I would suggest whether, for the unhappy occasion of having to carry one very big engine, you ought to sacrifice so important an element for the general security of your ship for all sorts of other cargo. I do not think the argument holds ground. Therefore I suggest as most worthy of consideration a central bulkhead, and I do so because this central bulkhead has the advantage of splitting the hatch into two, as well as

dividing the ship into two; therefore the same hatch can be equally well laden in two divisions as it can be in one, always with the supposition that it does not make the hatch too big. As to those big hatches, I think with our modern arrangements you need not much mind what the size of the hatch is, because I think we have the power of making the hatch perfectly water-tight, and I think iron plates well contrived and iron hatches would in many cases be a great safety against danger.

The other point on which I will venture to touch is the spar-deck. I do entirely agree with the enormous value of the system recommended in this paper, namely, the system of the continuous spar-deck, and I do think that the continuous spar-decked vessel is the safest vessel that it is in my power to contrive or to conceive. Therefore, I do say it is a most important recommendation, given to us in this paper, that we should endeavor, as far as we can, to remove all the impediments which the taxation, or, which is the same thing, which the tonnage law, now puts in the way of having the large empty spaces closed in, but on the upper side of the ship. That would be the greatest safety, and therefore I would suggest that in all cases in which a tax is put upon tonnage there should be a very large margin given for open spaces near the top of the ship. That, I think, is a most valuable suggestion, and I hope this institution will use its endeavors to have that carried out. I have seen no end of ships which have been made unseaworthy merely because if they had been made seaworthy there would have been a very much larger tax upon the tonnage. These are, I think, very important points. There is another point which has been raised by Mr. Martell, and I do think it is really of very great value. I do not think that there is anything now either in ship-building tonnage or in commercial tonnage to render it desirable to have very narrow ships. I do not know; I hope gentlemen who are here will say whether they think there is anything at all which now gives, in wrong taxation or in wrong tonnage, a premium upon a narrow ship. I do not know it. A ship with considerably more beam can be made with exactly the same resistance as a ship of smaller beam by wise lines, and unless there remains some fine on the tonnage I give my most unqualified opinion in favor of a large increase of beam for the ordinary sailing ships. By large, you must understand what I mean—large with reference to obtaining stability; I do not mean merely large in dimensions. Then I beg permission to say that in every respect a more worthy steamer will be built by wider beam and finer ends than is built by fuller ends and narrower beam. I think I have occupied my ten minutes, and I think these are the main points which most directly grow out of this paper, and to which I think the attention of the legislature and steamship-owners ought to be directed. I would say in regard to shifting cargo only one word. The divisions which I have mentioned would be a great safety in preventing cargo shifting. Another great safety in regard to shifting cargo is the point mentioned, which seems very difficult to carry

out, namely, filling the divisions of the ship which hold the grain cargo right up to the deck. What the great difficulties are in the way of doing that I am not quite sure. I see some difficulties, but I also see the way of getting over them. I think that the difficulties would be diminished by the longitudinal central deck. I think it would be more easy to pack that deck quite to the top than it would be an undivided deck, and I also see certain arrangements that might be made which would enable the stowage of the grain up to the very top to be more easily carried out. There is, however, a small point which arises in regard to water ballast. My choice for water ballast is not to stow the water ballast in a double bottom, but to stow the water ballast in a compartment, of course, water-tight all around, with an iron deck on top of it, and in a compartment which, when not filled with water, can be filled with cargo. And the same point holds good in both. In a water-ballast compartment, if you fill it with water to the very top, it adds greatly to the stability of the vessel, but if you do not fill it to the top then the water becomes a shifting cargo, and, instead of an advantage, it becomes a disadvantage. These, I think are all the points I need remark upon.

Sir R. SPENCER ROBINSON, K.C.B., F.R.S., admiral (vice-president). As a sailor I should like to say a very few words upon this subject, the importance of which cannot be exaggerated, and which has been so admirably treated by all the speakers before me that I feel great trepidation in offering the very few remarks which I have to make upon it. I at one time felt a little bit frightened and unhappy at some of the very clever deductions of the last speaker. He rather alarmed me by the very strong opinion he gave that double bottoms were the cause of very many ships upsetting, and thus he seemed rather, I thought, to go against what I had even learnt in his school, and which I am sure I had learnt from many practical and able observations made in this hall and elsewhere—that water ballast was not a thing to be despised, but was, on the contrary, very contributive to the stability and usefulness of a ship. The little misapprehension, probably, into which I fell, from something that Mr. Scott Russell said early in his speech, was certainly dispersed by the latter part of it, and I concluded that he, like all those whom I have the honor to know who write or speak on the subject of naval architecture, with one exception—a very gallant admiral, who holds exactly the opposite conclusion—considers double bottom water ballast to be a very excellent addition to the stability and usefulness of the ship. I followed with very great attention, and I followed with complete concurrence, almost everything that Mr. Merrifield said, and I generally do, because I know no person who throws more light on disputed subjects, or who better throws the weight of an opinion, formed by mature study and great intelligence, on those subjects that he deals with, than Mr. Merrifield. I, for one, really do believe that the knowledge of the qualities of a ship is most essential to the command of that ship, and

as far as I can possibly influence anybody, I should say give to every captain of a merchant ship every one of those curves, and the very many other important subjects which occupy the draughtsman and the constructor of a ship—give them the load-line and give them the curves of stability—give them the length of the righting lever, and let them understand that the stability of the ship will depend on certain quantities of metacentric height and the length of arm that will right the ship, and let them understand the respects in which cargoes of different natures and different qualities, stowed at different heights from the floor of the ship, will affect her stability. I have the greatest possible belief that the more widely you diffuse that knowledge among those who manage ships, and those whose duty it is, under the captain of the ship, to load the ship, the fewer there will be of those great disasters which have been so forcibly painted before us, and which all of us so much regret, and greater security will be given to our ships in every way. I quite agree with what Mr. Martell has said on the subject of tonnage laws influencing, somehow or other, both the proportions and the safety of our ships. Those subjects, and many others, have been treated extremely well by the previous speakers, and it would be presumption on my part to attempt either to enforce them or to say more than that I entirely concur in what they have said. The only other word I have to say is this: I do not see myself any impossibility in putting upon the ship, in some place where it can be seen, those qualities of a ship which the constructor desires her to have—the depth at which he intends her to be loaded, the stability that she would have under various circumstances, with that draught of water; and in fact, as I have said before, the measurements of the stability can be ascertained by the length of her righting lever, by the position of the metacenter, and in other ways. There is one thing I should like to ask Mr. Martell, if he does not think it impertinent: I noticed in one of his statements—and it appeared strange to me—that he gave the stability of a ship, with a metacentric height of eight-tenths of a foot as very considerable, and quite what a ship ought to have; and therefore, if he gives the stability of a ship, with a metacentric height of only seven-tenths of a foot, as being extraordinarily bad, the difference between the two seems to my ignorant mind so great that if Mr. Martell would kindly explain how that arises I should be extremely grateful. I am sure I may say that I myself, and everybody in this room, have felt that we are extremely indebted for the very valuable and most interesting paper which Mr. Martell has read.

Mr. WILLIAM DENNY (member of Council). My lord, I can only agree with all the previous speakers in the high terms in which they have referred to this paper of Mr. Martell's. I believe this paper will be a starting point from which improvements will be made, and that the teaching in it will tend very greatly to a reform in the proportions of steamers. Mr. Merrifield in his remarks brought forward a subject

which has occupied very fully the attention of this institution, and which is of the highest importance. It is that the draughting office of a building yard ought to be a much more completely equipped affair, in the matter of scientific knowledge and scientific power, than it generally is at the present moment. Mr. Merrifield has not laid one bit too much stress on that. I think the expense of £200 or £300 more a year in the draughting office of a building yard to render it an efficient instrument would be no waste of money, and would be amply repaid in the future. Reference has been made to the question whether it is possible to give to the captain of a ship, or the captain of a steamer, or those who have to do with her, sufficient data as to her stability. Granting that a draughting office is equipped in the way Mr. Merrifield has recommended, there is no difficulty in this. We have in our own yard, as often as opportunity offered, carried out the ordinary admiralty experiment of inclining our steamers, and we have, partly by means of properly-arranged weights, and partly by obtaining a certain amount of discipline among the men, managed to reduce the time required for a double inclination of a steamer with two uprights to within the limits of an hour. I draw your attention to this matter because it seems to me that if the inclination can be done within an hour, then there is no chance of an extravagant cost in the doing of it, because an hour is just the meal-time of our working men. We have found we can carry out the inclination within that time with no loss of money, excepting simply the wages of the men engaged in the work, which are very trifling. Sir Spencer Robinson asked whether it is not possible for a captain to know something about the stability of his ship, and he pointed out that there may be too many niceties in supplying that knowledge, and that injury might thus result. It seems to me that there is no such very great difficulty in this matter being arrived at empirically by the captain of the ship. With very slight exceptions the same ship, at the same draught, and with the same metacentric height, will roll practically the same number of times. If that is the case, why should not the captain of a steamer when she has been laden run his crew once or twice across the deck, then stop them and take the rolling of his ship, count the number of oscillations she makes and log them before she starts? This is a simple matter not difficult to carry out, nor requiring high scientific knowledge. Mr. Martell has referred to the long poop and raised quarter-deck vessel, and I am very glad that in bringing forward this type of vessel Mr. Martell has done so much justice to the class. It is a class not favored upon my own river, but from its large number I have taken especial pleasure in studying it, and the result is that I am able to speak in favor of it from one point of view. It is almost the only class of steamer which will practically stow the same amount of cargo in the after part as she stows in the fore part. I believe if the gentlemen of this institution went into the matter thoroughly they would be astonished to find out how many badly-trimmed steamers

there are afloat, and I think our East-coast friends deserve great credit for having grasped and solved this difficult question of trim. Mr. Scott Russell asked if there were not over and above the tonnage laws some other empirical points which might induce vessels to be built too narrow or too deep, and I am very sorry, and I am sure Mr. Martell will pardon me, that following upon his most admirable paper I am obliged to refer to the rules of his own society as being a case in point. Some years ago I drew the attention of this institution to certain faults which seemed to me to be very apparent in Lloyds' numerals. These faults consisted in this, that while we were thoroughly agreed that the breadth and depth and girth of a steamer ought to rule her transverse scantlings, we had not the same agreement in thinking that those elements ought to be involved in deciding the question of her longitudinal scantlings—that is, the question of the thickness of her skin and stringers. Now, Lloyds' rules, as they at present stand, do bring in these points; they do militate against the increase of breadth, and they do militate against the increase of depth; they tax both of them. It is quite true that by certain precautions taken by Lloyds, with regard to the limitations of the depth and breadth, something has been done to remedy this, but not sufficient, and I live in hope to see the day when Lloyds' Society will in this matter improve their rules. I know it will be a matter of much difficulty to work out a new basis, but I do not think that that society should adhere to a basis which contains in itself a disapprobation of requirements which Mr. Martell very properly wishes to see satisfied.

Mr. HENRY LIGGINS (associate). My lord, when I notice the last words of Mr. Martell's paper I can quite understand the reason why so much sympathy should be felt with it. Mr. Martell says, "At the present time this question has become a matter of public importance." Now, as one of the public, having had the opportunity of noticing the behavior of ships at sea, I think that this paper is the most valuable as regards the lives of our fellow-men that has ever been read in this room, and it is quite impossible for us to render our thanks too warmly to so high an authority as Mr. Martell for giving us the information contained in his very valuable production. But the first paragraph which struck me as being of very vital importance to the safety of those who go down to the sea in ships is at page 3, where Mr. Martell observes, "and that of our large staff of surveyors whose duty it is to carefully survey all classed vessels on their arrival home from foreign voyages." Now, one of the great causes of loss at sea I am perfectly satisfied is this fact, that all ships are not classed. There is, unhappily, no law in this country to enforce a survey. A very large number of ships coming from a port laden with a cargo, pounds, shillings, and pence is all the owners know about vessels, and they are anxious to get them to sea forthwith on their return voyage. Those ships, perhaps, ought to be docked, and the owners would probably be glad

to dock them if time permitted them to receive the cargo awaiting for them to be taken on board. Valves go wrong, the plates around the valves, and the various cocks connected with the engine-room go wrong, and we have the memorable case of the *La Plata*, which I believe may be considered as a fair type of what happens on these occasions. I think the law should be made compulsory that all ships above a certain size, and carrying over a certain number of people, should be compelled to be put under the surveyors of Lloyds, or some other institution of the same kind, or under the surveyors appointed by the Board of Trade. I know when it was my pleasure to own ships I used sometimes to think the surveyors exceedingly harsh, but further experience proved to my mind the fact that they were able, through their experience, to suggest improvements and repairs which my less knowledge did not enable me to do. I have to thank them for making my ships better than I or my shipwrights knew how to make them. I think, therefore, that is an important element in this paper, and one suggestive of some alteration in the law by which the compulsory classification of ships should be required. With regard to the cause of losses, I have been of opinion, from the earliest time I have noticed such matters, that the disproportion in the dimensions of our steamers is the principal cause of loss. It is not confined to ships with shifting cargoes. Coal is a shifting cargo, though not so readily shifted as grain, and many other ships with general cargoes have been lost where there is no shifting cargo to account for it. Therefore, I believe that our ships as a rule are too narrow, and the effect when they get into a very heavy sea is this, that the ship will not rise on the water from the trough of the sea with sufficient rapidity, and the sea topples over her.

Now we come to the advantages which a spar-decked vessel possesses over a well-decked vessel, which is that the water is able very readily to clear itself, and a spar-decked ship, therefore, as far as that is concerned, is a great source of safety, because the water itself is at once withdrawn from the ship, and does not keep the ship immersed even if any cargo inside of her may have shifted. That very often happens in passenger steamers, and those who travel in passenger steamers must have observed that long narrow ships have always wet decks, whilst broader beam ships with a less draught of water are comparatively dry ships. Therefore I come to the conclusion that the great cause of the loss of ships at sea is their being too long and too narrow. With regard to measuring the spaces under upper decks for tonnage purposes, if it were not done this injustice would arise, that a ship might call at Lisbon on her way home grain laden, or with any other general heavy cargo from the Mediterranean, and might bring over cork, a valuable freight-paying cargo, and she might load herself up between decks with that cargo of cork, and if that space was not measured and paid for, it would be an injustice to other honorable owners who would not take advantage of that non-classed space in the same way. That is one of

then know what he would have to command, and if that in some way could also be recorded on the vessel—in some conspicuous way beyond erasement—no matter who the captain might be, that man would have before him the particulars for her loading.

There is one point which I certainly was much taken aback at myself, when my attention was first drawn to it by the nautical assessors with whom I sit. Their experience is this: That there are more ships lost during the first voyage after a change of captain than on any other occasion; and we had one captain before us the other day who told us that on three separate occasions he had remained on shore for the purpose either of business or a holiday; on those three occasions a fresh person had taken command of the ship, and in all three cases they had gone down. That, gentlemen, is somewhat staggering. He attributed it to the ambition that might be found to exist in the breast of every man who sees a chance of benefiting himself by being placed in command, because the mate in many cases has been substituted for the captain, and he has a reputation to make. He is anxious to make an expeditious voyage, and so gain favor with his owners. He may have attempted to keep too much canvas on his ship, or to have kept it on a little too long, with the result that I have told you. The masters of course vary very much in intelligence, because I need not tell you that there are masters and there are masters; but I do believe if it were made a point, ere many months elapsed there would scarcely be found a master in our mercantile marine who would not have made himself sufficiently acquainted with the question of stability as to enable him, with the help that I have already suggested, to see that his ship is properly laden when she goes to sea. I may be met with this observation, "Yes, you load with grain, and another time you load with coal, and a third time you load with iron, and the fourth time you have a general cargo." I am aware of it. It would be simply for the builder in the first instance when he delivers over the builder's certificate to the owner, or when she is registered at Lloyds—because there could be no difficulty in it—to give the information with reference to coal, grain, or iron; but with a general cargo there must be some difficulty, because as to that nobody could exactly say where and how the weights which would come on board under that head would have to be stowed. With reference to the use of water-tanks, or ballast tanks, I believe that they may be made to possess greater advantages than they do at present for assisting the master during his voyage, especially in long voyages. Owners are very apt now to load their ships heavily with coal for the purposes of the ship's consumption; that is, for the voyage out and home. After a few days out, he may have consumed 70, 80, or 100 tons, according to his daily consumption, and if the means were given him by the introduction of some small tanks, or by subdividing in some way the existing large ones, because they generally are very large, he might get water ballast into his ship, and so keep her pretty nearly, if not

quite, at the trim at which she left the port. We know perfectly well that in these days of competition that first cost must be borne in mind. There can be no doubt about that. At the same time we should not be too far carried away by a desire for profit or feelings of economy. With reference to some of our smaller ships and the way they are loaded, I regret very much that one of our original members, a ship-builder as well as a ship-owner on a small scale, is not present here to-day to be able to address you on this subject; but he did tell me of a fact the other day which I think you should all know. You are aware that the Plimsoll line or the Plimsoll mark is put on by the owner, probably, I suppose, after consultation with the builder. He has one vessel of a certain class, and that vessel has now been running for years, and she has just paid her way, but never returned any profit. She is working as one of a large fleet of vessels managed by a friend of his, and these other vessels have all proved profitable, and the reason he was told why his ship was not profitable was that he insisted on the position of the Plimsoll mark being so placed that his vessel when she went to sea had so many more inches of freeboard than those other vessels, and that the difference between the one and the other—that is, the extra cargo carried by the few greater inches of immersion in the other vessels—was a difference between a profit and just holding your own. That wants looking to, my lord, and I think as much as anything, even after this long series of years when we have heard so much of the Plimsoll mark. I am afraid that I have occupied my time. There are just one or two other points I should like to name, and they are these. We have had some little reference made to bulkheads during this discussion. Now, Mr. Martell recommends that shifting boards in the case of grain ships at all events should be carried down to the floors of the vessels. There can be no doubt it is the right thing to do. Mr. Scott Russell advocates permanent bulkheads. Mr. Bennett has just spoken to us of wooden bulkheads, but I suppose they are temporarily fitted, so that they are practicably shifting-boards. Now, if owners will pay proper attention to the shifting-boards and inculcate that duly in their captains, I believe that, as far as trade is concerned, the arrangement would be found a more convenient one than a fore-and-aft bulkhead, as suggested by Mr. Scott Russell. Now, one word about the loading. I have named to you that the loading is usually left to the stevedore, but Mr. Martell has told us, and it may be news to many of us, that the port warden at the port of Montreal possesses such power at the present time, and for some time past, I may add, over the shipping loading there that not a single grain-laden vessel has been lost. I can only hope that this paragraph in Mr. Martell's paper may receive every consideration at the hands of the parliamentary committee, or such members of it at all events who may return to Parliament after their Easter vacation. Mr. Martell says, on page 22, "It is necessary to bulkhead off the part of the hold that is not to be utilized, so that the remainder can be properly

filled up." I can tell you that a case came under my own notice the other day, where a large lower mainhold had been partly filled with coal for the use of the ship, leaving the forward part of it empty—no bulkhead at all across the ship at the end where the cargo of coal was stowed—the consequence of which was that as soon as the vessel got into a seaway the coal went any way it liked, and the ship was lost. I have to thank you very much for your attention and kindness in having listened to me, and I can only plead for having occupied so much of your time the interest I feel in this most important subject.

Mr. WILLIAM JOHN (member of council). My lord and gentlemen, I must say that it was with some surprise I heard Mr. Scott Russell lend his voice in favor of the idea that double bottoms, as ordinarily fitted, are sources of danger, especially as he did it without qualification. Now, we all know, I think, in this institution, that whatever effect the double bottom has on the stability of the ship is due, as Mr. Martell said and explained and fully demonstrated, to its effect in lifting the cargo. Beyond that it has no effect whatever. Now, how does the matter stand in regard to an ordinary merchant steamer? I contend, my lord, that if there is any ship in the world that ought to be safe against capsizing it is a merchant steamer, because the weights are lower than in any other form of vessel that you can imagine. If we look for a moment at an iron-clad ship, which has to carry above the water heavy weights, guns, and masses of iron on the decks, and compare that with the weight above the water in a merchant steamer, the difference is enormous. Every one knows that those war ships are made safe, in spite of having to carry heavy weights very high up, and the extent to which a cargo in a merchant ship is lifted, by a double bottom of the depth of any of these on the wall, is infinitesimal, compared with the effect of lifting weights in an iron-clad ship; and the same thing applies to a sailing ship. In a sailing ship we carry weights of masts and rigging, 70, 80, or 90 tons, an enormous distance above water, and yet the ship is made safe, and stands up and is navigated in spite of that overhanging top-weight, and in spite of the pressure of the wind upon it. There is nothing that should tend to capsize a merchant steamer to compare with those tendencies, either in a merchant sailing ship or in a war ship of any kind. If we look at a merchant steamer with a double bottom, about 3 feet deep, as they frequently are, and remember that the floor of a ship ordinarily would be 2 feet, we see it is only a question of lifting the cargo a foot or so apart from dunnage. It is even less than that in some cases; so that I say the effect has been grossly exaggerated in the public mind—the capsizing effect of these water-ballast double bottoms; and for that reason I could not help feeling a regret that Mr. Scott Russell should have lent his name to the cry that has been propagated in reference to them.

There is one point more. Mr. Merrifield has referred to ship calculations, and I agree with much that he has said, and also with much that

fell from Mr. Denny in that respect. I think it is a pity we do not have more calculations with reference to the stability of merchant steamers. I do not go so far as some of the speakers have, to say that it is necessary to make elaborate calculations for all steamers afloat, because the thing is impossible; and it is unnecessary, for this reason, that there are hundreds of steamers afloat, and hundreds of sailing ships, built one after the other with but slight modification one from the other. Those that have been going safely for years are taken as a sufficient indication of the stability of their successors, and it is only in particular types of ships that it is necessary to make calculations, and those calculations should, in my opinion, be elaborate and extensive, and made as widely known as possible. Mr. Scott Russell and another speaker referred to deep tanks in preference to double bottoms. Well, there is a good deal to be said on both sides. One speaker said he had for years found these deep tanks answer very well. On the other hand, in some cases they have not answered well. The fact is, that to give a ship a certain amount of stability when she is to go across the Atlantic light, or on any other voyage, you must carry a great deal more water ballast if you put it high in the ship than if you put it low in the ship; and when you come to carry a large mass of water in deep tanks, it is a very difficult thing to keep them tight and sound, and it is a dangerous thing if this large mass of water gets adrift. I may say that these deep tanks have been taken out of ships because of the difficulty and expense of using them as water-ballast tanks. That is an experience on the other side. Middle-line bulkheads have been referred to as being necessary things. They are very desirable under some circumstances, and very great nuisances under others. With a grain cargo, a middle-line bulkhead is unquestionably a very advantageous thing, and it is frequently fitted temporarily, and in some cases owners have gone so far as to put an iron bulkhead in—a permanent one; but, in cases of that kind, ships are generally employed in the grain trade, and not changed from that into general trades; at any rate, it has been found in those ships that the advantages more than balance the disadvantages. But in many cases that I have known the difficulty arises in this way: If you regard this middle-line bulkhead as put there for strength you may carry it through the holds of a ship, but perhaps you cannot carry it through the engine-room; and I have seen it abandoned in a vessel of very trying dimensions—a very shallow vessel—where the owner was willing to have a middle line or bulkhead through the hold; but because he could not carry it through the engine-room and boiler space without entirely altering the arrangement, he had to abandon it, and get strength in another way. Then I would say, with reference to this question of capsizing, that it is purely a question of beam and freeboard, and, unless those points are attended to, it is impossible by any other means to avoid similar calamities. Mr. Denny drew an inference which was perfectly legitimate, by saying that if beam was of such importance, and depth,

surely Lloyd's should do as little as possible to hamper ship-owners or to handicap improvements in this direction. I say I am sure that the committee of Lloyd's registry would be the last in the world to wish to hamper improvements or alterations in the types of ships which would increase their safety. I know the particular points and elements in our rules, with which Mr. Denny does not agree. It is an old question—an old quarrel between us. It has continued now for some time, and I am very glad to find that Mr. Denny has thus far advanced. Before, it was a question of principle, but I think you will have noticed that to-day he says it is a question of degree. He admits, with us, that the dimensions—the breadth, the depth, and the girth—should come in in questions of transverse strength. He also says that in reference to longitudinal strength—the plating—we do put penalties for extreme proportions. If a ship is of extreme proportion of length to depth she has to have a certain extra strength longitudinally; and if we do not go so far as Mr. Denny would induce us, or wish to induce us to go, I should wish to point out it is a question of amount, not of principle, and it is a question which I am sure will be, as it always has been, treated purely from the point of view of the good of the ship, and the ship-owner, and of all concerned.

Captain SYMINGTON. My lord, Mr. Denny has said that merchant captains can find out the stability of their ships with very little trouble to themselves. As a merchant captain, I say it is impossible to this day to do so. The necessities of trade involve work being carried on in such a hurry that the ship is driven out of dock before her hatches are on, and the crews of our steamships in the present day are such a small figure as compared with the work which at times they have to do. If you wait until you get down the Channel before you endeavor to arrive at the stability of your ship you import another element, perhaps, of the sea or the waves, or perhaps the motion, and we cannot do it without very great difficulty. I am very glad to hear that this institution, or some naval architect, has recommended that we should have papers indicating the stability, and containing every information that scientific men can give us. I have commanded two large steamers from builders who refused to give us any plan at all of the ship. I am at present in command of a large steamer that has eighteen orifices under water, no plan of which was given us, and I think that is another element of danger which Mr. Martell has not touched upon. The engineer may have had a plan, but we like, although we are not scientific men, to know where the holes are in a ship that the water may come through. That is another element of danger which the captain has to deal with besides the cargo. We know how to stow our ships, but the necessities of the trade drive the things down pell-mell at the last moment. We have cotton on iron and iron on cotton. Whenever we go abroad it is very much alike. We go to Australia, and we have ores—copper ore, zinc ore; we have tallow; we have wool—all coming helter

skelter—and we are obliged to take them, and we do not know at times what to do. I am very glad to have been able to say these few words, and I hope that I am not out of order.

Mr. HENRY H. WEST (member). I think I shall not be improperly compressing Mr. Martell's remarks if I say that the causes of unseaworthiness may be summed up under four principal heads: first, unsuitable design; second, structural insufficiency; third, defective equipment; fourth, improper use. I am glad to hear Mr. Martell say that structural insufficiency is not in question. Mr. Kirk has drawn my attention to one item of defective equipment which everybody must admit is very important, but which Mr. Martell has not mentioned in his causes of unseaworthiness, though I have no doubt it has occurred to him. I refer to insufficient engine-power, especially for crossing the Atlantic. The second and third points—structural insufficiency and defective equipment—not now being in question, I turn to the first and the last—unsuitable design and improper use—and I take it that the two must be considered together, because they are so intimately related to one another. It is perfectly clear that both form and proportion are elements of design, and a suitable design is one in which these two points, amongst many others, are rightly adapted to the purpose for which the vessel is intended. The necessities of trade call for great variations in these two elements, and when we find that even in ordinary sea-going vessels the coefficients of form vary from under .6 to over .8, and the ratios of depth to breadth from .5 up to .93, I think we must see that the naval architect cannot be limited in any way as to these features of his design. He and the owner have to discuss what is wanted, and when the owner has decided what he wants, the naval architect and the builder provide him with that article. It then becomes the duty of the owner to use it with due regard to the qualities he has imposed on the builder. Designs that are suitable for one purpose are not necessarily suitable for all. This is a point that I think has not hitherto been sufficiently pressed home. If an owner has a ship that is not adapted for a particular purpose, it is his duty either to alter her purpose or to adapt her to it. If he is going to carry a homogeneous cargo which will so raise the center of gravity of his ship as to make that ship unsafe in point of stability, it is his duty to take in sufficient ballast, even at the risk of having to leave some of the cargo out. Ships fitted with water ballast have facilities for doing this which other ships do not possess. I think that instead of denouncing particular forms or dimensions and proportions of ships, we should rather impress on the owner the imperative duty of using his ship with due regard to her special qualities.

Mr. WILLIAM M. FENNING (associate). My lord, before this discussion closes I should like to allude to one point which I think, though not directly connected with it, really has a very important bearing on the whole case with regard to the safety of vessels, and that is the

question of insurance. I had the honor, some years ago, of reading a paper before this institution on that very subject when the matter was very much before the public, and I then had a very strong view, which experience has since confirmed, that really and truly the whole of this question is a mere money question. I believe that in the nineteenth century the naval architects and ship-builders of this country are quite able to build a ship which is practically indestructible, but their better judgment is hampered by the requirements of commerce and competition. The ship-builder is not told to build a ship that must be absolutely safe, but he is told to build a ship at the least possible cost which shall carry the greatest amount of cargo between two given points in the least possible time, with the greatest possible economy, and, if possible, with due regard to safety. Then comes the question: What is due regard to safety? I believe myself that human nature steps in here. If the ship-owners, and the owners of the produce carried in these ships, themselves had to pay for their loss, you would find that a very superior and safe class of ship would be built, far superior to any of the vessels that we have now heard of, even in this most valuable paper which has been read to-day, one of the most valuable I have ever heard in this institution. We are now, in 1880, building a class of vessels manifestly unfit for the purposes for which they are required. It is a very great question, and how is it to be dealt with? The fact is, that between the people who ought to bear the loss, and the loss itself, there is a buffer, and that buffer is insurance; and although you may think that it is a very extraordinary thing that the underwriters should go on year after year sanctioning a condition of affairs which is draining their pockets, putting aside all question of loss of life and that sort of thing which is involved, because that may be looked upon as sentimentalism, and I am now looking upon it only from the hard-money point of view. Why do they do it? Simply because they are unable, from their want of combination, to combine together to insist that the contract they make with the ship-owner shall be carried out. The essential part of that contract is, that the vessel, when she starts on her voyage, shall be seaworthy, and the difficulty is, that when they come to a court of law and declare that such and such a vessel has proved herself to be unseaworthy, you will get fifty or sixty, or any number of witnesses you like, to say that she was seaworthy, or ought to have been, and the underwriters are so sick of going to courts of law, and the supposed disgrace connected with it, that they pay away, day after day, and so increase this condition of affairs. I think it would be a great thing for this institution—and ten years ago I had hopes that something of this sort might be done—if it could, to lay down an axiom that it is possible to build a perfectly safe and practically indestructible vessel. That has not yet been done. If instead of its being a question of a lot of witnesses, the axiom could be laid down that such and such a vessel can and should be made safe for a given weight, underwriters would then take care

that their contract was carried out, and we should have a better class of vessels and fewer lives would be lost. I make these remarks because I think that, as the question is coming before Parliament, all sides should be attended to, and the question of insurance appears to me to be really the key-note of the whole thing.

Mr. RAVENHILL. I hope your lordship will not rule me out of order if I say two or three words with reference to the matter of insurance.

The PRESIDENT. We cannot have a reply.

Mr. RAVENHILL. I do not wish to reply; but I merely wish to tell this institution that I could have quoted cases to them, when I was addressing them, where the amount of insurance has been largely reduced, and the ship has been lost on her next voyage.

Mr. GEORGE DUNCAN (associate). My lord, I should like to have the opportunity of saying a few words with reference to the paper which has been read to you. I think it is a very able and very important paper indeed in the interests of the general community of this country, and particularly of the ship-owning part of it. It appeared to me as I sat here that there have been one or two points overlooked in the discussion. The discussion has gone very much in this direction, as if ships were built for carrying grain cargoes and nothing else. Now, that is a very secondary part of the carrying that ships have to do, although no doubt an important part thereof. Although by the providence of God and to the advantage of this country, a large proportion of grain is carried here, still that is not the article that employs the shipping of this country in so very important an amount as to require that ships should be constructed and should be dealt with as to their loading with reference to grain cargoes alone.

In addition to that I think that something else has been overlooked; that is to say, in speaking of the stability of the ship. I think it has been overlooked that a ship may be made, in the direction which is indicated by stability, to be too stable. That is one of the evils that I have a great deal more to do with than the other. I commanded a sailing ship, and have had a good deal to do with carrying large quantities of material to India, and my difficulty has been very generally to take care that my ships were not made too stiff. I had the misfortune, in consequence of having to seek a warmer climate during the last winter, to be obliged to leave the country, and I traveled in one of the Peninsular and Oriental ships. We fell into a gale of wind in the Bay of Biscay, and she was very restless. I fished about to see how that was; I was told that she had 600 or 700 tons of railway iron in her bottom. That was what was the matter with her. Both sides of the question are to be considered. You must make ships of fair proportions that for general purposes will be stable if fairly and properly loaded, and there is no question at all but that Mr. Martell's is undoubtedly the way to cure any question of stability in these water-ballast ships. Certainly if the water ballast—the double bottom—raises the cargo so high in the vessel, you

raise the center of gravity so far up that she is just as apt to turn and sail with her deck down as her bottom, and that is a very dangerous state of things. I have seen a ship that was a very stiff ship and had plenty of bottom too. There are vessels that carry such things as copper ore. They put a trunk like a V, made 3 feet wide at the bottom, so as to bring the center of gravity higher up. I once sailed in a ship round Cape Horn where we had only some few tons of ore above the hold beams, and I assure you she behaved in a way that was a caution. I laid in bed making sure that I should be called before the watch was out, to gather in the wreck of the masts from her being too stiff. Both sides of the question have to be considered. I am very glad, indeed, it has come out here to some extent that the character of vessels has been greatly damaged by the idea which many ship-owners have, that by increasing the length of the vessel, and thereby getting a greater displacement, you can have that vessel propelled through the water with the same power. The great authority on ship-building in my time was Hetherington, and his recommendation was that the length of a ship should be three times the length of her beam, but he said he would go a little in the direction of lengthening her; he would go to two-sevenths of the length for her beam, but we have got on to five times and six times, and when we began to build steamers we made them six or seven times the length of their beam. Then it was found that these vessels, although having a great deal of length in them, still by putting 30 or 40 feet in them it was found that there was more stability fore and aft, and that they were as easily propelled as they were when they were shorter vessels. But when we came to make them seven, eight, nine, and even ten times the beam, then that property went away altogether. That has been proved to demonstration by a number of these scientific gentlemen here, and that is one of the elements which I think requires to be put before British ship-owners in the most forcible way. I will put it in as plain terms as possible. You can get a vessel that will carry the same weight of cargo, 2 feet or 2½ feet broader, propelled as fast by the same engine as it would be if it were 2½ feet narrower and 30 or 40 feet longer. I believe it would make the greatest possible difference in our ships if they would shorten the vessels and make them somewhat wider. As a ship-owner, when I have a vessel built, I have required the builder to give what we call a buttock line, and I modify the ship's section by this, cut perpendicularly half from the center to the side, so that I could see, as you can from the shading of the pictures which are around the wall, that she had a curve in her fore and aft, so that when she had to get over the seas the after end would get down, and that is a very important element in helping her to rise forward. In the same way in scudding, if you want the vessel not to be pooped she must be moderately sharp forward so that the bow will get down and the stern will get up. When you make them ten times the beam you do away with this element altogether. I believe that to be the case, because I have

it demonstrated by those vessels which Mr. Scott Russell can tell us about, because he knows both ships' lines, and I am glad to see that we are to have a paper here on the subject. By putting two model vessels of exactly the same displacement and carrying the same weight, the one considerably broader than the other—by hanging a 2-pound weight on a pulley at the end of a tank you would see exactly which vessel came first to the end of the tank. That is a clear illustration without the scientific knowledge which many gentlemen have of displacement, and that plainly can be shown. It is clear that you can get a vessel to carry as many tons of cargo to be propelled by a certain number of horse-power, to be broader than you build them just now, and considerably shorter. I think that to be a great improvement in ships. Now, my lord, with reference to what was touched on as to measurement. I think that is a matter that this institution, of all others, should endeavor to impress on the government. I believe that all vessels ought to have a cover right over them from end to end; that there never should be a well where 200 or 300 tons of water might fall on the ship, and before she could deliver herself another 200 or 300 tons might come on board of her—she would roll to windward, and before she could free herself another one might come. I believe that ships should all be covered over with a spar or an awning deck, on those short voyages particularly between Ireland and Scotland, and the coast of England and the Continent of America. In these vessels the deck passengers are obliged to stand out on deck in the spray, and the cattle that are on board have to endure all the hardships of dirty nights and the spray going over them, when the owners would readily have made these ships very much safer and fit for the passengers and cattle. They might stand on a platform very much higher than they do now if the government would agree that this part should not be included in the registered tonnage, but reserved, under a penalty, for passengers and live stock. I think the government should do everything it can to encourage the covering over of vessels fore and aft. With reference to the well, and the ship-owners of the north country having found out a way to trim their vessels, as has been said by Mr. Denny, I think that if you had the fore-body fuller and the after-body thinner you could perfectly dispense with that well. I was very much astonished, indeed, to hear Mr. Scott Russell find fault with water ballast. Now, you know he was the first great inventor of water ballast, that is to say, in his noble experiment of the *Great Eastern*. I will not say she is an experiment. She is a noble ship. She has a tremendous quantity of room—empty space in the bottom—and she has carried tremendous weights of cables high up in her, and she did it all the better because they were lifted up in her. I feel that the lifting up of a weight in a vessel is of great importance. I know the captain of the port at Quebec that has been so much commended with reference to these vessels. He is a Captain Dick, who

was bred a ship-builder in Aberdeen, my native country, and he is a plain practical man. Now, I will show you how he goes on the water-ballast principle. He does not want these heavy grain cargoes put too low. Say that a ship has 20 feet depth of hold. She has 20 inches floor timber, so that a considerable space under her ceiling is empty, still he requires them to put an 11-inch deal edgeways across the bottom of her, and four boards on the top of that, lifting the cargo up a very considerable piece from the bottom, because the center of gravity being pretty well up the ship behaves well and does not go back with a jerk, but will go back steadily and readily. I commanded a ship in 1840, and I scudded across the Atlantic that year—the year the *President* was lost—and many large ships that were stiffer than my ship was were lying-to in a heavy gale. As the sailors say, she went nearly on her "upper leathers." She laid down, but she went along very steadily, and she would not go farther than a certain length, because she had a high free-board, and with that kind of ship the least wind in her sails keeps her steady. There are a great many elements with reference to the question of stability which require to be considered, besides making the ship just stiff enough.

Mr. NORMAN SCOTT RUSSELL (associate). I should like to say one word about this question of water tanks as against water ballast, because it seems to me that the question is not fairly put before the meeting. It is a very important question, and as far as I can see the meeting seems pretty well divided on the subject. The great danger of the water ballast, and the danger entirely of water ballast is, not when the ship is filled with water, but when it is empty. I only speak of water-ballast spaces where the water-ballast space is very deep. If the water-ballast space is only as deep as the floor, naturally then there is no danger, and it may be filled with water or it may not; but if, as in some ships, the water-ballast space is made very deep, when the ship is empty it is a great danger—it may be a danger and may cause the ship to upset, because when she is empty the center of buoyancy, or the center of upsetting force, is much higher than it would be when there is no water-ballast space. You must remember that the two ships are not the same. I would put a water tank, and I do not want the water-ballast space. I cut off the latter, and my ship in the water is a shallower vessel, and has more stability. I think, probably, that one of the great objections of the ship-owners to the water tank is that they like a free and open ship. They like her with as few bulkheads as possible, but I think if the government—if the Board of Trade and Lloyd's were to insist, as I think they ought to insist, that more bulkheads should be put into a ship, that the owners would then object less to fill one of these with water and use it as ballast, or more of them, as required. I must say I think that Lloyd's ought to insist on that very strongly, because not only does the bulkhead give transverse strength, but it also gives great longitudinal strength to the ship, because it keeps her always in shape.

Now, by the Plimsoll line we have the draughts of ships when loaded fixed. The public generally, I think, is under the impression that with numerous bulkheads these ships are comparatively safe, but in a great number of ships that now are running, there are such large compartments in the ship, that if one of them were filled the ship must go down, and as far as bulkheads are concerned, she might just as well have none in her at all. I think that Lloyd's should insist that the ship be divided into so many compartments that when she is fully loaded, if one of them at least be filled, she will still float.

Mr. DUNCAN. I should just like to say that there was an important element with regard to this question of ships carrying grain cargo from Montreal. A large portion of the cargoes that are carried from Montreal consist of white pease, the worst cargo of all that goes on board any ship—small round white pease.

The PRESIDENT. As no gentleman rises to continue this discussion, I think we may consider that the time has come when it may be closed. I cannot refrain from saying that I do not think I have ever in any of our annual sessions heard a more interesting, practical, and important paper read than the paper we have heard from Mr. Martell this morning. I think you will all agree with me that the discussion to which the paper has led has been worthy of the paper itself, and that it has been conducted by some of the most distinguished and able members of this institution. Gentlemen, of course I feel that it would be presumption in me to suppose that I can add anything to the remarks which have been made by the very able and scientific men who have spoken upon the subject of this paper of Mr. Martell's, but perhaps I may be allowed to say it strikes me we may draw from this paper, and from the discussion, two satisfactory and practical inferences. The first practical inference—a very important practical inference derived from two sources—which appears to me to be so satisfactory is, that those losses of vessels of which we have had so many to deplore during the last two winters, which have been referred to in such feeling terms during this discussion, are for the most part preventible. Then I say it strikes me there are two sources by which they are mainly caused, the one is imperfect and careless lading, the other is imperfect construction of our ships. The paper which Mr. Martell has read has given us two remarkable instances, one of each sort, and I cannot help referring to them. With regard to the lading, I would refer to what he told us about the regulations for the lading of ships at Montreal, and I would remind you that the local authorities of Montreal imposed a fine of $40 for every case in which the port regulations were disregarded. This fine was so ridiculously low that ship-masters used to pay it as matter of course, and load their ships as they liked, and numerous losses used to ensue. In consequence of this the fine was raised to $800, and since that time not a single grain-laden ship from the port of Montreal has foundered at sea. I think that is a very strong statement with regard

to what it is possible to do by judicious local regulations. The other point is, perhaps, even more important, because it does not refer to a local regulation. I will only read this short sentence from Mr. Martell's paper: "It is only those intimately associated with the mercantile marine who see how often, day by day, sometimes comparatively in small things, the tonnage laws tend to prejudice the safety of ships." Now, here we have another practical grievance I may call it. The one seems to admit for the most part of local regulation; the other is evidently a question for legislation and government interference, and no one can have heard this paper or this discussion without feeling that by some judicious regulations like those at Montreal, or by the interference of the government in a matter in which I think the government are bound to interfere, if it is found to be necessary for the preservation of human life and the protection of property, some such result should be attained. I say it is very satisfactory to my mind to hear that for the most part these melancholy cases are preventible by human law and human regulations. I am quite sure that I shall only meet the wishes of every one in this room by proposing a vote of thanks to Mr. Martell for the very able and interesting paper which he has read to us. Mr. Martell, I beg your pardon, I should have asked you whether you wished to reply.

Mr. BENJAMIN MARTELL (member of Council). My lord and gentlemen, I can only express my very great thanks for the manner in which this paper has been received, and I am very glad, indeed, to think it has met with such a full discussion, and that the observations have been made upon it which we have heard. I have very little to say, because Mr. John has kindly taken the objections *seriatim*, and replied to them, so that really there is very little left for me to say. There was one question put by Sir Spencer Robinson which I should like to reply to. He drew attention to the fact that in a spar-decked ship referred to in my paper, the height of the metacenter was only eight-tenths, whereas in the three-decked ship there is a difference only of one-tenth, that is, seven-tenths, and he could not understand why one is so satisfactory and the other is so unsatisfactory. That really is embodied in what I have been advocating with regard to the desirability of building vessels having greater freeboard. It is a question of freeboard rather than of metacentric height which affects the safety. In one case the freeboard is only 4 feet from the water-line to the deck, and when that vessel is inclined over to the gunwale it is found that her stability very soon begins to diminish from that point; but if you have 3 feet more beyond that point, as in the spar-decked ship—that is, a 7-foot side—even with the same height of metacenter, that vessel as she becomes inclined down, her stability goes on increasing and she can incline to a much greater angle before she comes to her maximum stability. That shows the great desirability of encouraging vessels having greater freeboard. That is a question of greater importance than even a little increased breadth.

I quite agree with the remarks of Mr. Duncan that we may go too far in increasing the breadth. It must be confessed that, as you have to carry all kinds of cargo, instead of going to great extremes with regard to breadth, it would be much better to regulate their stability to some extent according to the loading. I have said that in all sailing ships they are obliged to do so, and there is no greater difficulty, if the attention of the ship-owners is drawn to the importance of it, in doing it in a steamer than in a sailing ship; and, no doubt, now that attention has been so thoroughly drawn to this matter, there will be greater attention paid to the loading than has been hitherto the case. With reference to what I have mentioned about dividing the double bottoms, it is frequently the case now that the tank is divided into two or three parts, so that you can fill the tank with 60 or 80 tons of water; and, therefore, you are enabled, if you fill the fore part, or the afterpart, to regulate the trim of the ship as well as to increase the stability to just the extent you require. I may say that the dividing of these double bottoms in that way has been done to some extent now, and, no doubt, that will be still further adopted. With regard to Captain Symington's remarks, as to the eighteen orifices under water, it is very evident that these may constitute a source of danger unless they are carefully attended to, and nothing is so important, I think, as that the captain should have a detailed drawing of all the openings in his ship. I know that some owners of the present day insist on obtaining that, and I cannot understand how, as stated by the speakers, a builder of ships could refuse to supply the owner with such a very important drawing. We know in all sailing ships, where the keels used to have a camber for fear they might be strained in docking, we used to give a drawing of the curve of the keel; so in steamers, a drawing of all parts of the ship should be supplied to the captain for his information, and on it every pipe and opening in the ship should be represented. If I were an owner I should insist on that being done, and I should certainly look upon that as a very important matter. I think there is very little else for me to reply to. Mr. West made some remarks with regard to defective equipment. That is very important, but it is perfectly impossible to go into all these matters in a paper of this size, although I should like to have had a little more time and space to consider them more fully.

TWENTY MINUTES WITH PASSENGER STEAMERS "ON THE LONG FERRY."

By JOHN R. RAVENHILL, Esq., *member of Council.*

[Read at the twenty-first session of the Institution of Naval Architects, March 18, 1880; the Right Hon. LORD HAMPTON, G. C. B., D. C. L., president, in the chair.]

The following paper was prepared for our last annual session, but withdrawn from circumstances beyond my control, and although a paper has been read during the present session of the Institution of Civil Engineers on "the passenger vessels of the Thames, Mersey, and Clyde," and in the discussion that ensued reference was doubtless made to some of the matters I treat upon, I have left my paper as originally prepared, and I offer no apology for bringing the subject under your notice, feeling, as I do, that some information about this station, and the earlier vessels employed on it, is worthy of record in our transactions.

A stranger passing up or down the Thames at the present day would learn with surprise that in the early days of river steam navigation the marine engine factories and ship-building yards on its banks took a very prominent lead, and that the Gravesend and Margate stations were in fact the nurseries from whence emanated the light-draught water vessels first employed on the Rhine, the Rhone, the Saone, the Seine, the Lake of Geneva, and subsequently on the Volga and Danube and on the Nile and Indian rivers; these vessels were also the pioneers of the packets employed in the Channel passenger and mail-packet service—a class of vessel which may be said to have culminated in the present well-known Holyhead packets.

Gravesend, at the early date of the Norman conquest, occupied an important position connected with the port of London, and the *water passage* between them, or, in other words, that portion of the river Thames, was known as the *Long Ferry*, and was a great highway for merchandise and passengers. The traffic was carried on by sailing boats, called tilt-boats, and the last of these did not disappear until some twenty years after steamers were first placed on the station, the *Duke of York* finally succumbing in the year 1834.

The extension of the traffic appears to have first attracted the attention of steamship owners and others some sixty-five years ago, and a paddle-wheel steamer commenced running on 23d January, 1815—the *Margery*, of 70 tons burthen and 14 horse-power. She appears to have made the passage between the two places on alternate days and to have continued to ply for a few months, during which time, however, it was no uncommon thing for her to have to lay up for ten days at a time for repairs, and at the end of her first season she was withdrawn. In 1816 she was succeeded by the *Thames*—70 feet long, 15 feet beam, 74 tons

burthen, and fitted with an engine of 16 horse-power—which had run the previous year on the Margate station. She performed a daily service to and fro to Gravesend, except on Fridays. A second vessel ran in conjunction with her the following year—the *Sons of Commerce*, of 80 tons burthen, with an engine of 20 horse-power. The service became a daily one and both vessels ran on Sundays, and in 1821 they carried 27,291 passengers; these figures rose rapidly, and, in 1825, 71,469 passengers are recorded to have traveled by them.

The General Steam Navigation Company, that had been formed some few years previously, observing this great growth in the traffic, partly due to the improvements made at the town quay, placed some of their vessels on the station and great rivalry was created, with the usual reduction of fares. This lasted to the end of September, when they retired, and the public once more found themselves in the hands of the old company, but the latter not only raised their fares to their former rates but relaxed in their attention to the public, and so exposed themselves to further competition. On the 25th August, 1828, Messrs. Barnes & Miller, steam engine manufacturers, of Glass House Fields, Ratcliffe, placed the *Sophia Jane* on the station, with an engine of 50 horse-power on board, and the following season saw the first vessels of the Gravesend and Milton Steamboat Company running, viz, the *Kent*, the *Pearl*, and the *Essex*, and competition was sternly continued.

The year 1830 witnessed the opening of St. Katherine's Wharf, and on the 9th April the *Harlequin* steam packet left on an excursion trip to the Nore, and back, with 400 passengers on board—the first excursion trip I find on record. The Old Gravesend company immediately availed themselves of this wharf, and the rival company of a few weeks later obtained access to Fresh Wharf, and passengers ceased to land and embark in waterman's wherries.

The want of similar accommodation at Gravesend produced a very unfavorable impression, and although the corporation and inhabitants at once took steps to provide a pier, all their efforts for a time were defeated by the strenuous opposition of the watermen, who could only regard public improvements with the narrowest views, and who opposed one being built by every means in their power. They struggled as those of London had done before them against hackney coaches in 1634, stage coaches in 1673, and Westminster Bridge being constructed in 1736. But the necessities of the public carried the day, and four years later, on 29th of July, 1834, the Town Pier was opened with great *éclat*, the *Star* landing 500 passengers from London, and subsequently, in conjunction with the *Comet*, making an excursion down the river. On the following morning the latter came alongside and embarked passengers for London. The Star Steam Packet Company had been formed during the previous autumn, and when, soon afterwards, the Terrace Pier was opened, the vessels of this company were removed there.

In the year 1840 the Brunswick Wharf, in connection with the Black-

wall Railway, was opened as a landing-place for passengers, and the numbers to and fro to Gravesend in that year reached 812,854, and for the three following years the average exceeded 1,000,000 per annum—*one million and three-quarters* being the highest numbers ever subsequently recorded in one season.

The steam packets on the station belonged to five companies, who owned *seventeen* vessels between them:

	Vessels.
The Diamond Company	5
The Star Company	5
The Blackwall Railway Company	3
The Thames Company	2
The Eagle Company	2

(See Appendix A.)

With such a passenger traffic to deal with, I need scarcely remark that competition ran high to secure the confidence and patronage of the public.

The hulls of all the earlier vessels employed on the station were constructed of wood, but from the time iron was introduced as a material for ship-building, great rivalry as to the merits of the two materials had existed; and no stronger evidence can be required than the challenge which emanated from the captain of the *Ruby*, one of the Diamond Company's vessels, the fastest of the wooden fleet then running on the station, to the captain of the *Rainbow*, a new iron vessel brought round from the Clyde* by the General Steam Navigation Company. The challenge was an offer to run from London to Margate and back for 200 guineas, and was concluded in these words: "There are plenty of builders and engineers on the Thames who will equip a good timber-built steamer to beat and be much stronger than any of the new-fangled iron steamers."

An accident, however, happened shortly afterwards, that so clearly demonstrated the advantages of iron as the material for the future, that only a very few wooden vessels, on the diagonal system, were subsequently laid down for passenger river traffic. The *Prince of Wales* had been built of iron for the Margate Steam Packet Company, by Miller, Ravenhill & Co. (designed by Edward Pasco), at Blackwall, in 1843, of the following dimensions:

Length between perpendiculars, 180 feet.
Breadth, 22 feet.
Depth in hold, 10 feet.
Burthen in tons, old measurement, $429\frac{3}{94}\frac{5}{4}$.
Description of engines, beam (removed from the *Royal George*).
Description of paddle-wheels, common.

* See Mr. Laird's remarks in the discussion at end of paper.

Diameter of cylinder, 46 inches.
Length of stroke, 3 feet 6 inches.
Horse-power, nominal, 136.
Speed in knots, 12.75.

At the time of launching, as the vessel was sliding down the ways, the cleat on the bow gave way, in consequence of the bolts breaking, and let the vessel down so that the bilge came in contact with the wharf. The steam-tug lying off in readiness to tow the hull into the East India Docks was immediately attached to her, and subsequently the *City of Canterbury*, commanded by Captain Large, belonging to the Herne Bay Company, gave her services, but only for ⅞ chains and the towing hawsers to be snapped and broken again and again; ultimately the vessel was forced off by screw-jacks and two tug-vessels, cutting her way deeper into the concrete and planking of the wharf, until she assumed the position represented in Plate V; and at that period the distance, measured from the face of the wharf to the point of contact of the vessel with the surface of the water, was 110 feet. During the latter part of this anxious time a tug was kept attached to the stern, to prevent, if possible, the receding tide from producing any ill effect on her fore body. The whole of the deck in the center of the vessel was left unfastened for the reception of the machinery. When completely afloat it was found that the shear of the vessel was not broken, and that she had received no injury except that the bow was twisted in consequence of the tow-rope having been let go accidentally by the tug, and thus exposing the vessel for a few minutes to the sweep of a strong ebb tide.

On examination it was found that three of her frames were broken and one of the plates cracked, occasioning a considerable leak, which was accompanied by no other inconvenience than that of filling the bow compartment as far as the first bulkhead, and after hauling the vessel into dock the necessary repairs were effected in four days.

The *Prince of Wales* ran for the Margate Steam Packet Company for some seasons, and then became the property of the General Steam Navigation Company, and, after being fitted with new boilers and feathering wheels, the *Prince* remained a favorite vessel on the station for upwards of thirty years.

In addition to the accident above narrated being an incident in shipbuilding, it had considerable influence with the late Robert Stephenson in proposing the Britannia and Conway tubular bridges, and gave him considerable confidence in carrying them out.

But to return to the Gravesend station. After running their own vessels for some seasons, the Blackwall Railway Company withdrew them from the station, and entered into an arrangement with the Star Company to run from the Brunswick Wharf, Blackwall, in conjunction with their trains to and fro from Fenchurch Street. The vessels, all engined by Miller, Ravenhill & Co., were as follows:

Names of vessels	Built in—	Name of builders.	Length between perpendiculars.	Breadth.	Depth.	
			Ft.	*Ft.*	*Ft.*	*In.*
Meteor	1844	Miller, Ravenhill & Co	170	18	9	0
New Star	1847	....do	180	17	9	0
Jupiter	1849	....do	165	18	9	0
Mars	1852	Money Wigram & Sons	180	18	10	0
Venus	1854	C. J. Mare & Co	180	18	9	6

Names of vessels.	Burthen in tons O. M.	Description of engines.	Description of paddle wheels.	Diameter of cylinders.	Length of stroke.		Horse power, nominal.	Speed on trial in knots.
				In.	*Ft.*	*In.*		
Meteor	274$\frac{34}{94}$	Beam*	Ordinary	37	3	0	80	13.26
New Star	271$\frac{88}{94}$	Oscillating.	Feathering	34	2	9	70	13.97
Jupiter	265$\frac{70}{94}$	....do	....do	37	3	0	80	14.3
Mars	291$\frac{88}{94}$	... do	... do	39	3	0	90	14.0
Venus	291$\frac{88}{94}$	....do	...do	39	3	0	90	14.71

* Removed from the *Planet*.

During the time this service was continued no better one existed, and it was one which, from the very great increase of the traffic on the river, it would now be impossible to perform. The express service, both in the morning and afternoon, between Fenchurch Street and Gravesend, occupied, with the tide, about one hour and a half—against the tide some twenty minutes longer; and the *Jupiter*, *Mars*, and *Venus* were in turn employed on it.

The opening of the North Kent Railway to Gravesend did not seriously interfere with this traffic, but the cheap fares subsequently of the London, Tilbury and Southend Railway, together with the facilities of access to and attractions offered by other railway companies to the public in other districts, eventually told their tale, and the service was totally discontinued in 1855, and the fleet sold and dispersed in 1856. The vessels of the Diamond Company, which for some time had made an arduous struggle, had previously been withdrawn, as also had the Thames Company's, and other vessels running to Hungerford Market.

Although the passages between Blackwall and Gravesend was comparatively but short, the service was a trying one for the boilers; the vessels had to start with a good pressure of steam—generally just kept under blowing-off pressure by the use of the donkey—and the fires could not be eased at the end of the passage until the vessels were

close alongside the piers; again the donkey was brought into requisition—fire-doors and smoke-box doors all thrown open, to check, as far as possible, the steam from roaring off.

In the year 1851—the Great Exhibition year—the *Jupiter* ran, between the 29th March and the 14th September, over 17,250 knots, being laid by for general overhaul and boiler cleaning on three different occasions, each occupying a day, a contrast to the state of the service in 1815.

In Appendix B you will find some particulars of the scantlings of the hull which are interesting as a record of what was done in 1850. Plate V shows you a half midship section and the method adopted for attaching the wooden shelf and deck-beams to the hull.

You must remember that nearly all, if not all, of the early iron vessels for the River, Margate, or Channel stations were fitted on this plan, and the weight of the iron work in their hulls was in proportion to their length × breadth × depth.

As the vessels running up the Pool were withdrawn, the directors of the Woolwich Steam Packet Company availed themselves of what they considered to be a fair opening for an extension of the traffic, and placed on the station their then well-known packet, the *Dryad;* her speed was 12.6 knots on the measured mile at her trial, and although this was far short of the speed of the Star Company's vessels, they considered that, from her handiness and smaller size, she would be enabled to go in and out from the piers more readily than her larger opponents, and that this, combined with a smaller expenditure of fuel, would enable them to compete successfully for the traffic on the station. Their anticipations were so far realized that she was followed by vessels of a larger class, possessing greater speed, the *Nymph*, *Elfin*, and *Oread*, and subsequently by the *Metis* and *Doris*.

Names of vessels.	Length between perpendiculars.		Breadth.		Depth.		Gross tonnage registered.	Horse-power, nominal.
	Ft.	*In.*	*Ft.*	*In.*	*Ft.*	*In.*		
Nymph	123	6	14	5	6	9	88	36
Elfin	148	2	13	9	7	9	109	50
Oread	151	5	14	9	7	2	103	50
Metis	141	0	16	3	6	8	94	40
Doris	130	4	15	7	6	6	78	40

As you will remember, the service was extended to Sheerness, and the old rivals—the Woolwich and the Watermen's companies—were amalgamated. This new joint company in 1865 became the owners of the first saloon steam packets that were placed on the Thames, having purchased them in the Clyde. On this latter river the original *Iona* was the first steamer, I believe, built on this principle that attracted

the attention of the public, and she became a favorite with them; others followed with similar results, and in the year 1865 two vessels of this description were built by Messrs. L. Smit & Zoon, at the Kinderdyk in Holland, from a design furnished by Mr. T. C. Hide, of London—an associate of this institution—fitted with engines of 140 horse-power by Ravenhill, Salkeld & Co., for the Prusso-Rhenish and Lower and Middle Rhine Steam Navigation Companies.

These proved such a success that two more of somewhat larger dimensions were laid down in 1870, all the above-named parties being engaged in their construction.*

The two first performed the distance between Cologne and Mayence in *eleven hours fifty minutes;* the larger ones in half an hour less, being *capable of carrying, each of them*, 1,000 passengers. They were constantly employed in the conveyance of troops and stores by the Prussian Government during the Franco-German war. As their scantling is as light as any that has come under my own notice, I have given you certain particulars of them in Appendix C; also their sheer plan and half-deck plan in Plate VI.

They have done good work and continue to be largely patronized on the Rhine.

Names of vessels.	Length between perpendiculars.	Breadth.	Depth.		Burden in tons, O. M.	Description of engines.	Diameter of cylinders.	Length of stroke.		Horse-power, nominal.	Pressure of steam on boilers.
	Ft.	*Ft.*	*Ft.*	*In.*			*In.*	*Ft.*	*In.*		*Lbs.*
Freide	240	27	6	6	.....	Direct action, inclined cylinder.	46	4	0	140	25
Humboldt	240	27	6	6	.....	....do	46	4	0	140	25
Wilhelm	260	25	7	6	.....	....do	46	4	0	140	30
Kaiser	260	25	7	6	.....	... do	46	4	0	140	30

On the dissolution of the Star Steam Packet Company the *Jupiter* passed into the hands of the Dover Mail Steam Packet Company, who overhauled both the hull and machinery; a new boiler was fitted, iron deck-beams were substituted for the original wooden ones, a new deck, 2½ inches thick, was laid throughout, and bilge pieces were attached to the bottom, to enable the vessel to take the ground in Dover Harbor. On the completion of this work the Board of Trade, after survey, granted a passenger certificate for the summer season, but the admiralty mail packet surveyor of that day refused to give one; hence arose the anomaly that whilst you might cross the channel yourself in the *Jupiter*, any letter that you had previously posted could not accompany you.

Ultimately turned into a blockade-runner, after a severe struggle in the Bay of Biscay, poor *Jupiter* fell a victim to Neptune.

* See Correspondence at end of paper.

Three other accidents to vessels of this class, in addition to the one to the *Jupiter*, that came under my notice during this series of years, were as follows: In February, 1844, the *Elberfeldt*—belonging to the Lower and Middle Rhine Company, built in 1840, by Dichburn and Mare, with engines by Miller, Ravenhill & Co., and of the following dimensions: Length between perpendiculars, 170 feet 10 inches; breadth, 22 feet; depth, 8 feet 6 inches; burden in tons, O. M., 403; horse-power, nominal, 110—after having, in the first instance, crossed in perfect safety from the Thames to Rotterdam, was making a return voyage to London for new boilers. On nearing the English coast she fell in with a brisk gale on the morning of the catastrophe, about 6 a. m., and her hull began to work and strain heavily; as the Nore light was approached, about 3 p. m., she gave way in the engine-room, and the water rushing in she doubled up and sank. The captain and crew, having received timely notice, the boat was ready for immediate use, but the weather was so rough that three, out of a crew of sixteen, were unfortunately lost.

The second accident was to the *Concordia*, also belonging to the same company, built and engined by Miller, Ravenhill & Co., in the year 1846, of the following dimensions: Length between perpendiculars, 175 feet; breadth, 19 feet; depth, 9 feet; burden in tons, O. M., 314.$\frac{13}{94}$; horse-power, nominal, 100. She left London for Rotterdam in the mouth of August, with a party of ladies and gentlemen on board, was caught in a gale of wind off Harwich, and was for some hours in a most critical position. The iron work of the hull began to buckle and strain, the wood-work about her decks also strained, and it became necessary for the crew and passengers to avail themselves of everything that was on board that could be made into a shore—the engine-room through its entire length being heavily shored. At the end of a very trying voyage she arrived at her destination, but the straining of her hull had been such that its form had become distorted, and the speed subsequently obtained by her on her station on the Rhine was very disappointing after her trials in the Thames.

The third was to the well known Gravesend packet *Meteor*, in the autumn of 1854 (I believe); whilst running a back passage from Gravesend on a dark and foggy night, a large steamer came into collision with her, cutting her completely in two. Fortunately no lives were lost.

In the year 1864 Messrs. Caird, of Greenock, had built two saloon vessels to ply between Wemyss Bay and other stations on the Clyde, and on their passing into the hands of the Woolwich Steam Packet Company they came round from the Clyde to the Thames in the beginning of the year 1866. Falling in with bad weather the *Albert Edward* had to bear up for Queenstown, but the *Bute*, subequently known as the *Princess Alice*, continued her voyage, and reached her destination in safety. A few minor alterations appear to have been made in her in 1868, and in 1870 an intercostal stringer was introduced through the whole length of each

boiler-room; and in the spring of 1878, ten years after her arrival in the Thames, she received a thorough overhaul of her machinery and hull, and new boilers and bearers were supplied to her. After the usual Board of Trade survey she resumed her place on her station, and ran as required until the evening of the 3d September of that year. Her dimensions were as follows: Length between perpendiculars, 219 feet 4 inches; breadth, 29 feet 2 inches; depth, 9 feet 4 inches; burden, in tons, O. M., 251; horse-power, nominal, 140. (See Appendix D.)

It is far from my thoughts or desire to dwell on the awful accident to the *Princess Alice*: let us throw a veil over it, except in a technical sense, whilst I give you some particulars of both the vessel and the collision. The latter occurred as she was performing her up passage from Gravesend, and the dotted lines in Plate VI show you the angle of the collision. There was a blow, then a rebound, then a second blow—the *Bywell Castle* having struck her on her starboard fore-sponson, cutting through her side and entering the body of the vessel to the extent of at least 14 feet, in her progress cutting through the sponson, deck-beams, and paddle-beam until her way was brought up by the forward engine-beam, which was cut through, a short end being left projecting on the starboard side, the cast-iron maintop frame of the engines remaining uninjured.

The aperture caused by the collision was so large that the engine-room compartment was rapidly filled with many tons weight of water, and the middle part of the vessel, thus weighted and partially severed, commenced rapidly to sink, causing the two ends to be lifted up at a considerable angle, drifting down with the tide for about *four minutes*, when she finally disappeared. By this time she had become completely parted into two pieces; her fore body had turned round—head down the river—and in a direction nearly parallel to the after end.

The forward boiler was discovered between the two portions of the vessel at the bottom of the river uninjured, but the remaining long portion of the forward engine-beam was never found. It was probably wrenched away at the time the *Bywell Castle* damaged her bow. On her starboard side were four frames spaced 2 feet apart, required to be doubled and scarfed; and three plates were damaged, one of them being broken and requiring to be replaced.

After the two portions of the hull were recovered from the bottom of the river, I had, in connection with others, the opportunity of giving them a thorough examination, and not the slightest symptom of straining or working was apparent, either in any part of her plating or riveting, or in any other of her fittings, either in those made of metal or of wood, and the materials employed in her construction were of good quality.

This was so far satisfactory; but, let me ask, who can point out a river steamer that could withstand the collision of a large screw collier of the dimensions of the *Bywell Castle*?

During all these years, over which my remarks have extended, the amount of traffic on the Thames had been increasing, until, in the year 1874, the number of sea-going vessels arriving in London, including sailing ships and steam, foreign and coasting, amounted to 43,848, having a gross tonnage of 8,337,977 tons. In the year 1878 these numbers had risen respectively to 47,728 and 9,415,873.

These figures did not include the river craft, river steamers, and barges; about 7,000 of the latter were registered, and it was computed that about 1,000 of them pass daily from the docks below bridge into the Thames. During these four years twenty-one lives only had been lost through collisions of all kinds.

The Watermen's Company, an old guild dating back from the fourteenth or fifteenth century, possesses the greatest possible powers in connection with the navigation of the river, and passenger river steamers must be navigated above Gravesend by one of this body. Although, happily, the frightful calamity above alluded to may be taken as exceptional, the public is beginning to inquire whether the company has sought to elevate the position of its members by keeping pace with the times, and this enormous growth in traffic, by requiring a better education to be a necessity amongst them, or by seeking any standard of merit or knowledge from a member prior to his taking charge of a steamer with a living freight of several hundred people on board. The London Steamboat Company, at the present time the owners of a very large fleet of steamers plying both above and below bridge, are, amongst other matters in a bill now before Parliament, seeking for relief from this monopoly, the like of which does not exist on any other river; and all interested in the navigation of the Thames are watching its progress, and for the answers by which these and similar questions will be replied to.

Whatever may be the decision of Parliament, let us express the hope that it will be welcomed as a wise and just one by the British public.

APPENDIX A.—*Dimensions of vessels running on the stations belonging to the five companies.*

STAR COMPANY.

Names of vessels.	Length.	Breadth.	Depth.	Burden in tons, O. M.	Horse-power, nominal.
	Ft. In.	*Ft. In.*	*Ft. In.*		
Comet	135 0	16 0	9 4	163	70
Star	141 0	21 0	11 0	300	120
Vesper	155 0	18 0	9 6	250	80
Satellite	139 10	17 0	8 4	199$\frac{41}{94}$	70
Meteor	170 0	18 0	9 0	274$\frac{33}{94}$	80

APPENDIX A—Continued.

DIAMOND COMPANY.*

Names of vessels.	Length.	Breath.	Depth.	Burden in tons, O. M.	Horse-power nominal.
	Ft. In.	*Ft. In.*	*Ft. In.*		
Diamond	145 0	16 6	9 6	200	70
Pearl	103 0	17 6	9 4	152	60
Topaz	135 0	16 0	9 6	163	70
Ruby	160 0	19 0	9 4	280	80
Sapphire	170 5	18 1	9 6½	351	(†)
BLACKWALL RAILWAY COMPANY.					
Brunswick	146 2	19 1½	9 9	263	90
Railway	146 8	19 1	9 9	262	90
Blackwall	146 8	19 1	9 8	262	90
THE THAMES COMPANY.					
Sons of the Thames	140 0	17 0	8 3	199	56
Father Thames	141 6	19 2	10 0	254	70
THE EAGLE COMPANY.					
Eagle				149	50
Falcon				149	50

* This company shortly afterwards purchased the *Prince Albert*, length 155 feet, breadth 19 feet, 100 horse-power, and called her the *Emerald*.

† Atmospheric engines.

APPENDIX B.—*Jupiter.*

KEEL.—Of best iron 6″ × 1⅝″.

FRAMES.—Of angle iron 2″ × 2½″ × $\frac{5}{16}$″, spaced 1′ 3″ apart in engine and boiler room; forward and aft to be spaced 2′ apart, with reverse angle-irons 2″ × 2″ × ½″ on every alternate frame.

FLOOR PLATES.—Of plate iron 14½″ × ½″.

PLATES.—Garboard strake ⅝″, first strake from ditto $\frac{5}{16}$″, second ½″, bilge $\frac{5}{16}$″, from that to gunwale ½″.

BULKHEADS.—Collision, and one at each end of engine-room.

DECK BEAMS.—Of wood 5″ × 4½″, spaced 17″ apart, bolted (as shown Plate V) by ⅝″ bolts to shelf, 8″ × 4½″, attached to vessel's side by bolts of the same diameter, spaced 18″ apart.

DECK BEAMS.—In engine-room 6″ × 6″, with one iron beam 6″ × ⅜″, with double angle-irons on top and bottom 3″ × 3″ × ⅜″ between engines and boilers. Iron beams fitted over boiler.

ENGINE BEAMS.—Of wood 14″ × 14″, with an iron plate on the upper side 3′ 2″ × ½″, bolted through beams, and angle-iron on plate at fore end 3″ × 3″ × ⅜″. Wooden clamps 14″ × 5″ × 16′ long extend from paddle-beam to paddle-beam under these, and additional ones about the water-line, with plate ½″ thick attached on upper sides.

PADDLE BEAMS.—Of wood 11″ × 8″.

MAIN DECK.—Of yellow pine 2″ thick.

APPENDIX C.—*Rhine vessels.*

KEEL.—Of plate-iron $\frac{1}{2}''$ thick.
FRAMES.—Of steel $2\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{2}''$, spaced 21″ apart.
FLOOR PLATES.—Of steel $9'' \times \frac{1}{2}''$, amidships $9'' \times \frac{3}{16}''$.
PLATES.—Bottom plates $\frac{1}{2}''$ full, from thence to gunwale $\frac{1}{4}''$.
BULKHEADS.—$\frac{1}{8}''$ full.
DECK BEAMS.—Of steel $3\frac{1}{2}'' \times 1\frac{1}{2}''$, with deck-stringer plates $3' \times \frac{3}{16}''$.
DECKS.—Two, of yellow pine $2\frac{1}{2}''$ and 2″ thick.

APPENDIX D.—*Princess Alice.*

KEEL.—Of best bar-iron $4'' \times 1''$.

FRAMES.—Of angle-iron $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ full, spaced 2′ apart in engine and boiler rooms; forward and aft to be $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$, and spaced 2′ 3″ apart.

FLOOR PLATES.—Of plate-iron $8'' \times \frac{1}{4}''$ in engine and boiler rooms; forward and aft to be $8'' \times \frac{3}{16}''$, with one reverse angle-iron $2'' \times 2'' \times \frac{1}{4}''$ on the top of each floor, and carried up the bilge 3′ in the engine and boiler rooms; fore and aft $2'' \times 2'' \times \frac{1}{4}''$, carried in a straight line.

KEELSONS.—One in center of vessel, fitted between floors of plates, $10'' \times \frac{3}{16}''$, in engine and boiler rooms; forward and aft to be $10'' \times \frac{3}{16}''$, with two angle-irons $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$, riveted back to back through keelsons and reverse frames.

PLATES.—Garboard strake $\frac{5}{8}''$ bottom and round the bilge $\frac{5}{16}''$, from that to gunwale $\frac{1}{4}''$; before and aft the engine and boiler rooms the plates to be $\frac{1}{16}''$ thinner. All the bolts to be flush and double riveted, and longitudinal joints lapped and single riveted.

BULKHEADS.—Four. Collision—one at each end of engine-room and one in after-run, plates $\frac{3}{16}''$, with vertical angle-iron $2'' \times 2'' \times \frac{3}{16}''$, 2′ 6″ apart.

DECK BEAMS.—Main—$3\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ full, and for about 30′ fore and aft $3'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$, spaced, one on every frame, connected by small knee-plates. Cabin-floor beams $1\frac{1}{4}'' \times 1\frac{1}{4}'' \times \frac{3}{16}''$, connected by stanchions to the middle keelsons.

ENGINE BEAMS.—To be of three plates—vertical plate $10'' \times \frac{5}{16}''$, horizontal plates $18'' \times \frac{5}{16}''$, angle-irons $2'' \times 2'' \times \frac{1}{4}''$, with fore and aft castings to paddle beams. The horizontal plates connected together by five angle-iron brackets and plates equidistant in breadth of vessel.

PADDLE BEAMS.—Vertical plate $10'' \times \frac{7}{16}''$, with two angle-irons $3'' \times 3'' \times \frac{5}{8}''$ on the top, and one $2'' \times 2'' \times \frac{1}{4}''$ on lower edge, with one round stay, 2″ in diameter, from each end to ship's side.

STRINGERS.—On main deck $15'' \times \frac{3}{16}''$, with angle-iron $3'' \times 2'' \times \frac{1}{4}''$, and reduced, to 12″ at fore and after ends.

MAIN DECK.—Of yellow pine $2\frac{1}{2}''$ thick.

MACHINERY.—Diameter of cylinders, 44″; length of stroke, 3′ 9″; 140 horse-power.

APPENDIX C.

27 COURTFIELD GARDENS,
South Kensington, London, April 12, 1880.

DEAR SIRS: I understand that a member of your family, at present a student at the Royal Naval College, at Greenwich, has named to Mr. White (a friend of mine, who during my absence from London read a paper at our late meeting of the Institution of Naval Architects which I had prepared on river steamers, and who is a professor at the above college) that I had fallen into an error in connecting Mr. Hide's name

with the two last vessels that you built for the navigation of the Rhine, and fitted with our machinery, and that you designed the whole of the work connected with the vessels, and without any communication with him. If this is the case I shall feel obliged if you will write me to this effect, without loss of time, as I can correct my statement before the volume of our *Transactions* is printed; for I should be extremely sorry to put forward any statement that is not correct, or to deteriorate in the slightest degree any credit that may be due to your good selves, in connection with these two vessels.

I am, dear sirs, yours faithfully,

JOHN R. RAVENHILL.

Messrs. L. SMIT & ZOON,
Kinderdyk, Holland.

KINDERDYK, *April* 14, 1880.

DEAR SIR: In reply to your esteemed letter of 12th instant, we have the honor to inform you that a friend of us, Mr. Martin, has written already for us to the editor of the *Engineering* the following: "In your issue of 26th March last, p. 253, on 'Passenger Ferry Steamers' by John Ravenhill, there occurs a passage concerning the building of the second two Rhine steamers which must surely be an '*erreur de plume*'—at least it is not in strict accordance with the truth. It is therefore that I feel it but fair justice to the builders that it be rectified. The paragraph says: 'They proved such a success that two more of somewhat larger dimensions were laid down in 1870, all the above-named parties being engaged in their construction.' Whereas I happen to be able to state positively that the latter two vessels were built to plans made entirely by Messrs. L. Smit & Zoon, at the Kinderdyk, in Holland." You would oblige us very much by employing your good influence to rectify this.

We remain, dear sir, yours truly,

L. SMIT & ZOON.

MR. JOHN R. RAVENHILL,
27 Courtfield Gardens, South Kensington, London.

27 COURTFIELD GARDENS,
South Kensington, April 20, 1880.

SIR: On my return to town my attention has been called to a letter from Mr. Martin, of Flushing, which appeared in your journal of 9th instant, with reference to a paragraph in a paper written by me, entitled "Twenty Minutes with Passenger Steamers 'on the Long Ferry,'" and in which I alluded to the last new steamers on the Rhine; and as this subject has also formed a matter for correspondence between the builders, Messrs. L. Smit & Zoon of the Kinderdyk, and myself, I feel it necessary in justice to all parties to trouble you with the following statement:

As regards the *Freide* and *Humboldt* no question has arisen, and if I have fallen into any error in connection with the *Wilhelm* and *Kaiser* it has occurred, not from any desire to detract from any credit that may be deserved by any one in connection with them, but from the fact that Mr. Hide, just prior to his leaving London for India, accompanied me to the Kinderdyk, on my going there to finally arrange some of the details with the builders, and he handed to them a drawing which he had prepared the previous year in conjunction with them, and from which at that time at all events it had been proposed these *two* vessels should be built, and I now learn for the first time from Messrs. Smit & Zoon, under date of the 14th instant, that they did not follow that design.

The original drawings of the sheer plan and elevation of these two vessels have been in my possession for some time past, and are those from which the plate that is attached to my paper has been taken.

Yours faithfully,

JOHN R. RAVENHILL.

THE EDITOR OF ENGINEERING,
Bedford Street, Strand.

27 COURTFIELD GARDENS,
South Kensington, May 1, 1880.

DEAR SIRS: I annex a copy of a letter I forwarded to the editor of *Engineering* after the receipt of your reply to my letter of the 12th April, and which he has since published.

Trusting that the above-mentioned letter may be in all respects satifactory to you,
Believe me, dear sirs, yours faithfully,

JOHN R. RAVENHILL.

Messrs. L. SMIT & ZOON,
Kinderdyk, Holland.

DISCUSSION.

Mr. HENRY H. LAIRD (member of Council). My lord and gentlemen, I think we must all feel indebted to Mr. Ravenhill for his paper, as it may be looked upon as a record which will be published, with the volume of the proceedings of this Institution, of the earlier days of steam navigation on the Thames. Those individuals who themselves remember the introduction of steam are very fast passing away; and I think that it is one of the things that we are most short of—a thoroughly authentic record of the earlier efforts in the path of steam navigation, both for river and sea service. Mr. Ravenhill's late firm had so much to do with the earliest paddle engines that were made for vessels for river and sea service, that his information on this subject is, perhaps, as full and correct as any one else's can be? There is one point in the paper that I may perhaps be excused for alluding to, and that is with reference to the first iron ship to which the author refers. He speaks of the *Rainbow*—a vessel that was built for the General Steam Navigation Company, which came round to the Thames, I think, in 1838—as having come from the Clyde. As the *Rainbow* was really built by my late father at Birkenhead, and at the time she was built was the largest iron steamer afloat, and the one that attained the highest speed, I hope I shall be excused for correcting what was evidently a mistake. I do not recollect the *Rainbow* myself in her earlier days, although she lasted until a few years ago, but I have often heard my father speak of the interest excited by this vessel, 185 feet long, coming round here, and performing the service, first between London and Ramsgate, and afterwards, for many years, as a regular trader to Antwerp, with dimensions as to breadth in comparison to length, which at that time were considered rather startling. I may also say as to the remarks made with regard to the construction of the decks in those days, that I think the *Rainbow's* decks were constructed on the same plan as that explained here for the *Jupiter*, and other vessels of that class.

Mr. JOHN SCOTT RUSSELL, F.R.S. (vice-president). My lord and gentlemen, the *Rainbow* was indeed a very wonderful specimen of good naval architecture at the time she was built, and I beg to testify to that

because she had my admiration for many years. With regard to those other vessels I will say a word. I have built similar vessels to those described here as Rhine vessels. These vessels have crossed more than once from London to Rotterdam, but I think it quite right to say that if these vessels were really well fitted for the purpose they were designed for, namely, the navigation of the Rhine, they must inevitably be extremely ill-fitted for the navigation of the sea. Allow me to mention that the vessels I built were vessels in which I was limited absolutely to a ship of great length—200 feet long—of little breadth, and of extreme shallowness, because they had to go under bridges. I remember being limited to what was almost impossible, and, therefore, whatever faults were committed in these iron vessels—I am happy to say none of them sank, and therefore I am not excusing myself—really grew out of the purpose for which they were designed, which required extreme shallowness, a very limited breadth, a very limited depth, and great weight of engines in order to give great towing power. The only way in which I in the end succeeded in making very strong ships for that purpose, with the lightness that was required, was by using the longitudinal system as a substitute for the transverse system. By that means I was enabled to put light longitudinal bulkheads, which served also not only in the ship to strengthen the ship, but I made the cabins which stood on the top, and the side of the cabins also longitudinal iron bulkheads, so that I was able to get 16 feet depth for those longitudinal bulkheads by taking in the cabins on deck as a portion of the real structure of the vessel. That is all I have to say upon that subject. Now with regard to the *Princess Alice*. I knew her very well, because she was built by an old assistant of mine, now the head of a very large firm in Scotland. She was very well built for the purpose for which she was originally intended. She was built for inland waters. I need not say that inland waters do not at all subject ships to the same strain as sea-going ships are subject to.

The *Princess Alice* was very well trimmed for the purpose she was originally meant for. It was, therefore, quite reasonable to expect that she should come round from Glasgow to London even in a heavy sea without suffering any injury, and she did so; and finally it was quite within the range of the purpose for which she was built, that she should serve as an effective vessel on the Thames. I also examined that vessel after her destruction, and I have simply to say, as I think has been said before, that it is absurd to expect a long river steamer, built for river navigation, to have the enormous power necessary to keep another great heavy ship from running her down when she puts her stem right across that ship. There are circumstances for which the ship-builder can never be held to be at all responsible, neither properly can the ship-owner, because I know of no way of making such a ship strong enough to keep that larger ship out of her.

Mr. HENRY LIGGINS (associate). My lord and gentlemen, historically this is one of the most interesting papers we have had for a very long

time before this Institution, but I should like to supply one or two gaps which Mr. Ravenhill seems to have left, as far as my memory goes—and it goes back so far that I dread to think of it. It is a paper of great accuracy, but I may be allowed to say that the General Steam Navigation Company was established in 1824, and for some years had the good fortune to own an exceedingly favorite vessel called the *City of London*. She was very well known—there may be two or three gentlemen here who have traveled in her in days past—by her corkscrew funnel, that is to say, her funnel was painted in white and black stripes of a corkscrew form. She had a very good reputation for a great number of years, and was commanded by a gentleman who was extremely well known to me—a Captain Martin, who, for many years afterwards, under the Board of Trade of that day, was the harbor master of Ramsgate, and lived to a considerable age. There was another very celebrated vessel which I had the good fortune to travel in the first time she ever made a trip on the river Thames. That was the *Little Western*. She was at that time the largest river passenger steamer in Europe. She was a wooden vessel, built entirely for river traffic, and I think I am right in saying that she was the first paddle-wheel steamer that had those wheels called Morgan's wheels—that is, the feathering float-wheels. It was at that time by those on board, who were better judges than I was, a matter of remark that there was very little vibration in that vessel; and it was, of course, due to the wheels. I think she should be mentioned, if not in the paper, in the remarks which follow it, because for a number of years she was the most celebrated passenger steamer on the Thames—the favorite of the public—as she was the fastest and the largest. The last time I saw her she was doing good service at Gravesend as a coal hulk, and for aught I know may be rendering that useful aid to steam navigation now. Through the courtesy of one of the directors of the General Steam Navigation Company I had the good fortune, during my holidays, to be on the trial trip of the *Rainbow*. The *Rainbow* was considered to be a very remarkable vessel in that day, and I believe considered to be quite the fastest vessel for the purpose that had ever been built. I think Mr. Ravenhill is a little in error as to her intended purpose. I quite forget whether she ran to Gravesend, as the paper states she did, but she certainly was built for the General Steam Navigation Company for their Rotterdam trade. It is well known that she ran with great success in that trade. I think I may truly say that for thirty years I never heard of her having an accident, and I believe she was a great favorite with the passengers. I have made a passage in her at sea, and found her, as she had the reputation of being, one of the most delightful vessels you could possibly travel in. She, too, at that time was somewhat remarkable for her steadiness, because I perfectly well remember an old Fellow of the Royal Society saying to me on the trial trip, "We will try a tumbler of water on her bridge;" we did so, and not a drop of water was spilt over by the vibration of the engines. That was

thought at that time to be a great feat. Mr. Ravenhill omits also another celebrated vessel of the fast days, when the public had the advantage of competition between London Bridge and Gravesend; and I think I am not wrong in saying that, taking her all in all, she was the most beautiful and fastest little passenger steamer that was ever built. Messrs. Ravenhill constructed her, and she was called the *Vesper*.

Mr. J. SCOTT RUSSELL. She was a lovely boat.

Mr. LIGGINS. She beat the *Star* as a rule, but sometimes the *Star* did succeed in beating her. I had the good fortune to make a start with the intention of making a rapid passage once—with a desire to make the best passage ever made between London and Gravesend. We did the distance from London to Gravesend in one hour and ten minutes, the distance being 25 miles from London Bridge. It was a great feat. It was arranged with very good coal and extra stokers, and at a time when the tide had its full force—it was about half tide, or a couple of hours after the turn of the tide, so that she should have the benefit of the best of the tide all the way down. I do not give the steamer the credit of all the speed over the course, but the passage was made in one hour and ten minutes. I believe it was the quickest passage ever on record of any steamboat between those two points. Then with regard to the saloon boats of recent type; some of those boats I understand were blockade runners, which were never employed on their work because the American war happily terminated. They were of much stronger construction than the ordinary river boats, and had such a large deck area that it was considered desirable to put saloons on them. Entirely to Scotland is due the merit of having turned out the finest steamer for river traffic in the world—that is the *Iona*. They have, I believe, built the *Columba* since then. I have not seen her, but I suppose she is an improved *Iona*. The *Princess Alexandra*, of London, was one; the *Princess Alice* another; and the *Albert Edward* a third; and they all gave great satisfaction to the public. It is a matter of astonishment to me, that the channel service boats should be designed without any hints being taken from vessels that may be seen by taking the trouble to go down to the river side, of a kind eminently suited to that particular work. All that is required to make the passage between England and Calais pleasant, is larger boats than those in which at present we are cooped in, and saloons to guard the ladies more particularly from the spray and the effects of the bad weather which so often prevails in that stormy channel. With regard to the *Princess Alice* there is no occasion to say anything about her. All who knew her, as I well did (and I had a narrow escape of being on board of her on the day she sank, as I was taken off to Ramsgate instead), know that she was as nice a boat as ever floated on the river Thames, and as strong as a boat for that purpose need be; and anybody who has had my experience at sea must perfectly well understand that if a large screw

collier four or five times her size comes in collision with her, the result must be inevitable; and it must not be considered, because that happened, that there is any danger on the Thames in consequence of that. The causes were well known to those who investigated them. It was no fault of the ship-builder, and we hope we shall be free for the future from any catastrophe so serious, and that the present skill of the age will still continue to supply us with steamers which will be as great favorites with the traveling public as those of the past have been.

Mr. EDWARD B. BARNARD (associate). Mr. Ravenhill's paper is a very admirably-written one as regards the position of things at the time these boats began to run; but there is one thing which has only been named and not been specified—that is, with reference to what the Diamond Company did when the Star boats were running in conjunction with, and also opposed, I might also say, at certain times of the year, to them. Now, there were many boats in connection with the Diamond Company at the same time of day—older boats than the Star boats. I speak now of about thirty-five years or forty years ago, when boats were running on the river Thames connected with the Star and Diamond Company. The old Star boats were old wooden boats, and those which Mr. Ravenhill has last given us in his able paper are the newest boats made for the Star Company, and are iron boats. When the Diamond Company started, the *Old Pearl*, the *Old Diamond*, the *Ruby*, and the *Brilliant* were all old wooden boats, and ran to Gravesend for many years. They added to their list the *Sapphire* and the *Emerald*—the one which was called the *Prince of Wales*, renamed the *Emerald*. The *Ruby* was the boat which, to my certain knowledge, was pitted against every Star boat that came out—the *Meteor*, the *New Star*, the *Old Star*, and the *Old Jupiter* were all wooden boats, but the *Mars* was a new iron boat, and the *Venus* was an old wooden boat substituted for a new iron boat. The *Ruby* was pitted against every one of those boats. The *Meteor*, thirty years ago, if my memory is right, had her cylinders reversed out of the *Planet*, and a pair of beam engines put into her, and better engines never came off the river Thames than those which were supplied by the makers of those engines. They were supplied to the whole of the company's vessels; and I believe I may say, as a practical man, that I have been behind every one of them. I speak of the Diamond Company's boats merely to put them in juxtaposition with those of the Star Company, in order to consider what those boats did against the Star Company. I am in a position to prove—not that I have the documents with me—that the *Ruby*, a wooden boat of a light class build, made the quickest passage on record, with all things in her favor, from London Bridge to Gravesend Town Pier Light, which is 27 miles, mid-channel course, in one hour and twenty-eight minutes. I was on board at the time, and had the port engine in my charge, and the starboard engine was under the charge of the late Mr. William Dudgeon. That I can answer for as a fact. That vessel was at all times

pitted against the whole of the other vessels—the *Meteor*, the *New Star*, the *Jupiter*, *Mars*, and *Venus*. At that time of day when these new boats came out, they only used to run from Gravesend to Blackwall, the Diamond boats having probably the better chance because they had 300 yards start above them at the Town Pier as against the other pier, and previously to starting their steam was always fully up, and the wheels were always constantly kept revolving, so that the only thing was to let go the springs when the last kick of the bell was given, and away we went. I do not know how many times we have been knuckle and knuckle going up, and we have gone four times out of six into the Blackwall pier before the Star boats. I am not disparaging the Star boats, because they were beautiful running boats, but I am stating this as a thing that should not be lost sight of. There were three boats in fact—the *Wonder*, of Southampton, and the *Sapphire* Gravesend boats. Those engines by Seward were three atmospheric cylinders, doing very much the same work as those of the *Ruby*, but not quite. The engines of one of the other boats—the *Emerald*—were built by Messrs. Coates, of Newcastle; and the engines which were supplied were direct-acting engines by John Braithwaite. Those three boats have kept up an equal speed on the river to any of the Star boats.

Mr. BENJAMIN MARTELL (member of Council). My lord, I did not intend to take part in this discussion, had I not heard every speaker who has stood up to express an opinion upon this paper extol the wonderful properties of the passenger boats on the Thames. Now, I think of all the boats I have ever traveled in they are the greatest disgrace to this country, as a great naval architectural country. If you go on the Clyde, you have magnificent vessels for the service of that river. I have also seen in America the magnificent boats they have, suitable for their large rivers. On the Mersey they know how to build a boat suitable for the purpose intended, where if you have rough winds and wet weather you can get accommodation properly covered in; but on the Thames, if you go on board a passenger vessel there, you have in wet weather to protect yourself with your umbrella and stand a chance of its being blown away, or get wet through. I want to know how it is, seeing the great skill of naval architects, we cannot have constructed boats suitable for the purpose such as we see carried out successfully in other parts of the world. In this country the Thames is the only river where we do not appear to know how to build boats suitable to the requirements of the place. I have no doubt that a vessel built like the *Princess Alice*—a saloon vessel intended to go to Gravesend—would not be suitable to the upper reaches of the river. You must have smaller boats there, and flush-decked boats are sufficient. I sometimes go to Greenwich, and I should go oftener by boat if there were greater convenience on board, and if one could be protected from the inclemency of the weather. Why cannot we have vessels so constructed as to have some little saloon on the deck, that would protect persons from the

weather, and be suitable and convenient for such a journey as that? I think if the naval architects of this country were to lay themselves out with the steam ship-owners to have a boat constructed suitable for that purpose, they might have boats of proper size, with nice little saloons on deck, properly divided off below by iron bulkheads, which would render them perfectly seaworthy even if they were perforated in any one compartment. If you merely appropriated the upper part above the deck for accommodation, there would be no difficulty in dividing the lower part into any number of compartments by iron bulkheads, and such an accident as occurred to the *Princess Alice* could not, as it seems to me, lead to any serious injury to the vessel if it were divided out into a sufficient number of compartments. I merely stand up now to make a protest against these high eulogiums being passed on the passenger steamers of the river Thames, and to say I do hope to see that the experience and ability of our naval constructors will be utilized in producing better, more commodious, and safer vessels altogether for the passenger traffic on the river Thames than we have at present.

Mr. LIGGINS. I have only to say that I had no intention to pass any eulogium on the boats of the present day on the Thames, because I agree with Mr. Martell that with few exceptions they cannot be worse. The reason is that there are, on either side of the river, railways which prevent larger sized boats being profitable.

Mr. BARNARD. Mr. Martell, as I understand, is speaking of the vessels of the present day, but we have been talking of vessels which were running forty years ago. I do not know whether Mr. Martell will take that into consideration.

Mr. MARTELL. I would merely say, in reply to that, that Mr. Liggins invited us to go down to the side of the river, because we might see there the magnificent kind of boats that should be built for crossing the channel.

The PRESIDENT. Gentlemen, it only remains for me, I think, to express my great regret that Mr. Ravenhill is not here this evening to vindicate his own paper. I think Mr. Martell has been a little severe upon our boats upon the Thames, and I cannot quite agree to the comparison he drew between the boats upon the Thames and the boats upon the American rivers. Now, like Mr. Martell, I have myself been upon the Hudson and the Saint Lawrence, and have seen these boats, and traveled in them. What did I find? I found boats admirably well adapted to those magnificent rivers—rivers compared to which our rivers in England are mere brooks—rivers of which really we in England have no idea; and I think Mr. Martell will agree with me when I say that if the boats which are well adapted to those rivers were to be transferred to the Thames, we should find them ill-adapted to the navigation of our comparatively small rivers. I do not mean by that at all to say that our boats are not capable of improvement—I dare say they are; but I greatly doubt whether you would mend matters much by bringing the boats from the river Hudson down to the Thames.

ON CELLULAR CONSTRUCTION OF MERCHANT SHIPS.

By W. JOHN, Esq., *member of Council.*

[Read at the twenty-first session of the Institution of Naval Architects, March 19 1880; the Right Hon. LORD HAMPTON, G. C. B., D. C. L., president, in the chair.]

Many of those who have been at all intimately associated with the mercantile marine, and have given attention to its progress and development, must, I think, have been more or less impressed with two rather peculiar features or rather features which appear peculiar from their existence side by side. One is the change, or evolution, that is constantly going on in the sizes, proportions, and types of ships, to meet the changing requirements of trade. The other is the apparent stagnation that exists often for years together in structural improvements, or rather in the main structural arrangement of the material.

Mr. Martell has well illustrated the first of these tendencies, and has pointed out some of the dangers that may imperceptibly creep in, even when the progress is gradual and constant.

In regard to the other tendency, in structural arrangements, it follows almost inevitably that periods of apparent stagnation have to give way to periods of change, more or less violent, and at such times it behooves all who are interested to watch narrowly the principles involved, as well as their practical application, in order to lessen, so far as practicable, the risk of error. The present is unquestionably a period of great change in mercantile ship-building, and I propose to review briefly the nature of the transition now going on, and the steps which have led up to it.

It is well known that Mr. Scott Russell, many years ago, advocated the longitudinal principle of construction, and that he applied it successfully to many ships of the mercantile marine, notably to the *Great Eastern* and the *Annette*, the two which are, perhaps, best known to naval architects.

It is equally well known that the admiralty have for years adopted a modification of this system in the bottom of their iron-clads, known as the longitudinal and bracket-plate system. Mr. Scott Russell, in 1862, read a paper before this Institution on the longitudinal system, and described, with his usual force and clearness, the construction of the *Annette*, and the salient points of the system. Other papers have been read before this and kindred institutions on the subject, and numerous discussions have taken place; but in spite of all, the system did not take root in the mercantile marine.

Many theories have been advanced to account for this, and for the most part they have not been complimentary to the intelligence of mer-

cantile shipbuilders. Sometimes it was attributed to the obstruction of Lloyd's; but this was clearly insufficient, for the *Annette* herself was built under special survey, and received the highest class then awarded, viz, 12 A1, and several other longitudinally-built ships which preceded her were also classed in Lloyd's register.

My own conviction, looking back on the course of events from the present time, is, that the mercantile shipbuilders, and we must not exclude shipowners, for they have, perhaps, a still greater voice in this matter, were not so far wrong, under the circumstances, to adhere to the old system of transverse floors and tranverse frames.

But, however that may be—and I shall refer to it further on—the fact remains, that although introduced more than twenty-five years ago, the lead in longitudinal ship-building was not followed up, and until quite recently there had been no sign of its active revival.

At the time Mr. Martell read his paper on "water-ballast steamers," before the autumn meetings of this Institution in Glasgow, there had been only two or three small steamers built (since Mr. Scott Russell's early ones) on the longitudinal principle. Now, it is within the mark to say there are one hundred steamers built and building whose bottoms are constructed on the longitudinal principle, or what is perhaps better described as the cellular system, amounting probably to upward of 200,000 tons, and it is not outside the bounds of probability that a very few years will see the majority of merchant steamers constructed in this manner.

I have marked the date of our Glasgow meetings as one having an important influence on this change, and the connection arises in this way: In describing the different modes of constructing water-ballast tanks, Mr. Martell gave particulars of the construction of a little vessel in which he, together with my colleague, Mr. Cornish, and myself, were much interested, for the arrangement of floors and brackets was made in our office as an alternative to a proposal of the builders to achieve the same object by a different distribution of material. This was the *Fenton*, built by Messrs. Austin and Hunter, at Sunderland, in 1876. This is shown in Fig. 5, Plate X.

The arrangement attracted the attention of many, and especially that of some of the Clyde ship-builders, who almost immediately began to adopt and to modify it to suit the requirements of different size ships. It is the farthest from my wish to draw distinctions between different builders, but there is no doubt that Messrs. Austin and Hunter have the credit of first applying the bracket system in the mercantile marine, and that the great impetus was given to the movement in favor of this system by the zeal with which it was taken up by Messrs. W. Denny and Bros., of Dumbarton. Indeed, so largely did they apply it to ships of all sizes, and so strongly was it urged by Mr. W. Denny that the system is associated to a great extent, and rightly so, with the name of that firm. Again, Messrs. Denny raised the important issue with the

Board of Trade as to the tonnage measurement, and got the latter taken to the top of the double bottom, instead of, as previously, to the height of an imaginary floor. Nothing has added more than this to the spread and general adoption of this system, for it produces a sensible diminution of the tonnage and working expenses of ships so built compared with those built on the old system.

Many modifications and improvements have been introduced, and these I shall endeavor to point out, but before doing so it may not be uninteresting to examine the connection between the present movement in the mercantile marine and that of twenty-five years ago. The *Great Eastern* is of course the greatest embodiment of the longitudinal system, and will always be associated with the names of Mr. Scott Russell and Mr. Brunel. She stands apart as a wonder in naval construction, which I do not propose in this paper to discuss. We in this Institution know the longitudinal system chiefly as it was advocated by Mr. Scott Russell for all ships, small and large, and I might almost say it was a longitudinal system pure and simple. At least it was a system thorough and complete in itself, which abolished transverse frames entirely, but did not neglect the transverse strength of the ship any more than it did the longitudinal strength. The transverse strength was maintained by numerous transverse bulkheads and partial bulkheads, which gave rigid bearings to the longitudinal girders, and these latter transmitted the rigidity so obtained to the other parts of the vessel. The longitudinals also furnished the material for local strength, while together with the plating they contributed to the longitudinal strength of the vessel.

This system in the *Great Eastern* was associated with an inner skin or double bottom, as is well known, extending up to the lower deck.

In the *Annette* there was only a single bottom, but there are many points of extreme interest in her constrution which it may be well to recur to, and I have therefore shown on Fig. 1 the arrangement of her framing. An interesting sketch of this in perspective will be found in Vol. III, to illustrate Mr. Scott Russell's valuable paper before alluded to.

In that vessel it may be remarked that there was no ceiling whatever, cargo being stowed right down on the skin of the ship, and the tonnage measurements were also taken down to within a few inches of the bottom.

The registered dimensions of the vessel were 201 feet 7 inches by 30 feet by 26 feet 6 inches depth of hold, and she measured 741 tons. There were six water-tight bulkheads, well stiffened by angle irons, and there were ten partial bulkheads 13 feet apart. The longitudinal girders were continuous and about 4 feet apart, with single angles on their outer and inner edges 18 by $\frac{5}{16}$ in bottom and 14 by $\frac{5}{16}$ in top sides, and they were connected to the transverse girders, or partial bulkheads, by diamond plates, as shown on the sketch.

I may mention that the arrangements, as you see them in the *Annette*, were not arrived at suddenly, but were the result of improvements made

from ship to ship upon former vessels by the same builder. I will, for instance, mention one point which will be of interest to many at the present time. The diamond plates which are shown on the *Annette's* framing, and which are now finding their way into frequent use, were originally transverse covering straps extending on the inner edge of the web frame from the deck beam down to the keelson plate. Those plates of course fulfilled the same purpose as the diamond plates, but they did more, for they reinforced the strong places as well as the weak ones, which was a waste of material, and moreover left the inequality of strength as great as before. I was examining recently the plans of some of the earlier longitudinally-built ships, and was interested in noticing the steps by which the system embodied in the *Annette*—and a very perfect one it is of its kind—had grown up.

I must not omit to mention that the *Annette* was fitted with an iron deck, which was a by no means unimportant part of Mr. Scott Russell's system, and although rare in those days, it is a feature which has greatly extended in merchant steamers of later date.

I must now point out what, in my opinion, are the objections to the *Annette* type of construction that prevented its finding favor and extending into general adoption.

In the first place, the system requires a larger number of transverse bulkheads than is usually fitted, and this would be a serious disadvantage in most trades. In the next place, there is a want of facilities for working ceiling, and without close ceiling in the bottom, and ceiling, or battens, above the bilges to keep the cargo free from damage by sweat and bilge-water, iron vessels have not, and are not likely to find favor with either ship-owners, merchants, or underwriters. Again, the stowage would be greatly interfered with by the deep girders, extending as they did so far within the space measured for tonnage, thus rendering the cargo capacity small compared with the registered tonnage; and beyond this, the comparatively large areas of unsupported skin-plating would render her more liable to local damage from grounding, such as merchant ships have so often to endure. I do not by this mean such grounding as is involved in striking a rock at high speed, or beating upon rocks in a storm, which would imperil any single bottom ship, but the sort of scrapes in harbors and rivers that merchant ships frequently get into, and get out of, without damage, and without delay for repairs.

These objections are to my mind sufficiently serious to account for its non-adoption in the absence of any striking advantage in favor of the system. The advantage claimed was of course the great increase in longitudinal strength, and it was set down in this particular ship, and has been repeated in text-books, as 25 per cent. above the strength of a vessel built on the ordinary system.

The weak point in the argument was, however, the absence of any proof that a merchant ship of the same size, built to the ordinary scantlings, was deficient in longitudinal strength.

I am not aware that any calculations had been made, until a much later date than the building of these vessels, to ascertain approximately the greatest hogging and sagging strains to which ships were liable in a sea-way; and the results of all the calculations I have seen have shown that in small vessels of this size the skin-plating keelsons and stringers alone afford abundant longitudinal strength without the aid of the longitudinal system. Although this was not demonstrated at the time, I cannot but think that the absence of proof to the contrary deprived the main argument in favor of applying the longitudinal system to ordinary steamers of most of its weight, and prevented it carrying conviction to those who could fully appreciate the practical objections which I have alluded to. I have said nothing as to the cost or difficulties of construction, or the objection of builders to change from the old methods to new ones, although they were also elements antagonistic to the longitudial system; but I think their influence has been considerably exaggerated by most writers who have endeavored to account for the obstinacy of the mercantile marine in refusing to avail itself of the supposed advantages of the longitudinal system.

I must now leave for a moment the mercantile marine, and glance at the Royal Navy, because the longitudinal system for ship-building may be almost said to have migrated to the admiralty at the commencement of iron-clad ship-building.

In the *Warrior* and *Black Prince* a combination of the longitudinal and transverse systems of construction was adopted which has often been described. There were five longitudinals on each side below the armor-shelf with solid transverse floors worked intercostally between them, and inside of these, heavy transverse framing which extended up behind the skin-plating, the armor, and backing. The *Warrior* class had also two iron decks. These vessels were 380 feet long, and required considerable longitudinal strength, but it may be noted that their fine ends were not loaded with armor. The next iron-clad vessels of the *Minotaur* class were 400 feet long, and were moreover armor-plated from bow to stern, and required very great longitudinal strength, and it was in connection with these vessels, I think, that the importance of estimating approximately the maximum strains at sea became evident. From this we come to the *Bellerophon*, Fig. 2, which marks an important step, for in her the admiralty longitudinal and bracket system of construction was first introduced. This was also the first of the iron-clads fitted with a complete double bottom. An account of her construction will be found in Mr. E. J. Reed's valuable work on ship-building, and will be familiar to many in this room. Its merit in point of cheapness, lightness, and safety over the preceding iron-clads was unquestionable, and it has become almost the stereotyped system of construction for the bottoms of iron-clad ships all over the world. I will describe it briefly.

The vertical middle-line keel-plate, as well as all the longitudinal

girders, are continuous, and the bracket plates are fitted every 4 feet apart, with solid plates in lieu of brackets every 30 feet, made watertight in order to subdivide the double bottom.

There are no intermediate frames, so that the bottom plating is unsupported for spaces of about 3 feet 6 inches, and 4 feet amidships. The angles on the outer edge of the longitudinal are continuous, the transverse angles corresponding to our frames being in short pieces between the girders. On the other hand, the angles on the inner edge of the longitudinal girders are in short lengths, and the reverse frame is carried continuously through.

The double bottom extends up to the fourth longitudinal out from the keel to the bottom of what is the wing-passage bulkhead, and above this the construction of the vessel's side is transverse, and is dictated by the necessity for carrying armor, and has little in common with ordinary mercantile ship-building.

The inner bottom is worked flush, with single-riveted edge-strips below, in short lengths between the continuous reverse frames. And another point worth notice is, that the longitudinals are all placed square to the outer bottom, and continue to stand square to the body of the vessel as its form changes forward and aft, and following the lines of the plating, so that they have considerable twist and curvature, which add to the difficulty of construction.

Modifications of this section have, of course, been resorted to in the admiralty service, in the scantlings, and in the distance apart and number of longitudinals, to meet the requirements of ships of different sizes and form; but the general arrangement I have described was adhered to, and has, I believe, existed almost, if not down, to the present time.

The Indian troopships of the *Serapis* and *Crocodile* class were built on this system, and also the *Iris* and *Mercury*, in a somewhat modified form. The chief departures that I am aware of have been made by Mr. Reed, himself the designer of the *Bellerophon*, in his more recent designs for iron-clads for foreign governments built in this country, where the outside frames, instead of being in short lengths, were made continuous through the longitudinal girders.

I will now point out what in my opinion are the principal reasons which prevented this system, introduced some fifteen years ago, from extending itself to the mercantile marine. In the first place, the difficulties of construction are great, and this renders the process of getting the vessel in frame very slow compared with the ordinary system of transverse framing and floors. In the next place, the provision for local strength in the bottom has not been generally considered adequate to the requirements of the mercantile marine. I do not say it is insufficient for the purposes of the Royal Navy, as this is a matter on which the experience and authority of the constructors of the Navy must be of far greater weight than any opinion I could offer; but there can be no doubt as to the difference which exists between the conditions and

requirements of the mercantile and royal navies in this respect. The number of iron-clad ships in commission at any time is very limited, and they are commanded by picked officers, who are extremely careful to keep them off the ground; indeed, if they did not exercise this caution, they would be tried by court-martial, and would sacrifice their professional positions.

In the mercantile marine, however, where there are thousands of ships constantly making their way in and out of all sorts of harbors, and up and down crowded rivers, it is not possible to insure the same scrupulous care in all the officers, nor to prevent numbers of these vessels from getting aground in one place or another every week.

In consequence of this a large consensus of experience on questions of local damage is constantly being brought home to the minds and pockets of ship-owners and underwriters, which leads them to insist upon the vessels being made strong enough to bear ordinary rough usage without incurring the necessity for repairs every time they strike on a bar or touch the ground, or are left partially aground when they are taking in cargo, in home or foreign ports. It is no answer to them to say that ships are made to float, not to go ashore. They say they must do the work that usually falls to their share, and if they are not strong enough they ought to be made strong enough.

Hence, the great importance which has always been attached to substantial floors closely spaced and well tied up with strong middle-line and other keelsons, which distribute the strain so brought on the bottom.

Again, this bracket system naturally associates itself with a double bottom, and would be an extremely imperfect arrangement without an inner bottom, but a double bottom has neither been considered nor found necessary in mercantile ships for purposes of safety, and the only vessels fitted with double bottoms for carrying water ballast were until recently of only moderate dimensions, and such as did not require to adopt the longitudinal system for strength, and least of all in the bottom. Even in the larger types of steamers, in many of which a deficiency of longitudinal strength did doubtless at one time exist, the deficiency was in the top not in the bottom, and their need was iron decks, not a more or less complicated cellular construction in the lower part. Herein lies indeed the fallacy which has for years run through the claims put forward on behalf of the longitudinal system, both in mercantile and war ship construction.

There is not a doubt in my mind that the question of longitudinal strength has been as much magnified in relation to ships of war as it was formerly underrated in the mercantile marine, and although fortunately neither bias—if I may call it a bias—has led perhaps to much mischief, yet it is important that one should look the facts fully in the face, to realize the accurate bearings of the question. The existence of the longitudinal system of construction in our shorter iron-clads indeed

can scarcely, I think, be defended logically on the ground usually put forward, viz, that it gives such great longitudinal strength; for when we find that the maximum strain in this direction in some of them is only one or two tons to the square inch, the only sound deduction from such figures is that a great deal of the material placed in this direction is wasted unless it is placed there for some other purpose than longitudinal strength. Of course in the top, iron has to be added for purposes of armor protection, but it is equally clear that the longitudinals in the bottom would be better placed in any other direction if greater local strength could thereby be obtained. The defense of the system should therefore be based on the ground that it affords greater local strength, if it is so, rather than on the merits usually proclaimed for the longitudinal system.

I have been led so far in this direction because it is of the utmost importance at a time like the present, when cellular systems of construction are spreading so rapidly in ships of all types and sizes, that we should not be led to overrate any one particular feature of the change at the expense of others. It is well to note that it is not for its advantage in point of longitudinal strength that it is now being so largely adopted in merchant ships, but because of its association with water ballast.

It is curious, indeed, to note that the change is working upwards from small vessels to large ones, instead of coming about as has been predicted by the enormous growth in the size of ships necessitating the adoption of the longitudinal system.

Many of our large ocean-going steamers, of 400 feet and upwards, are provided with ample longitudinal strength by the simple method of iron decks, skin plating, and keelsons, without involving any excessive weight of hull, and the largest ship building at the present time, viz, 550 feet in length for the Inman Line, is equally well provided in the same manner. It is only, then, where an inner bottom is required, either for commercial purposes or for additional safety, that we may look for the cellular system replacing the old-established, simple, and well-tried mercantile transverse system of construction.

When we look to water-ballast steamers, however, the aspect of affairs is quite changed. Mr. Martell, at the Glasgow meetings, showed a variety of systems of fitting these water-ballast tanks; and I need not go over the same ground, but I wish to remark that the custom had become almost universal to fit the tanks on the floors, as shown on Fig. 3, but with varieties in the details, according to the practice of the different builders. In this way the tanks were practically an addition to the weight and cost of the ship, and, although they added appreciably to the strength of the bottom, they were not regarded as a necessary or integral portion of the structure.

Viewed in this way the system was not without its conveniences, for,

being an addition beyond the strength proper of the ship, it could be fitted for any portion of her length, or at any part deemed necessary for the purpose of ballasting and trimming the vessel. As a consequence, by some it was fitted all fore-and-aft, by others in the fore and after holds, but not in the engine and boiler space. In many cases it was fitted through the after hold only, or there and under the engines and boilers. And it had the merit that these tanks, or any portion of them, could be easily removed, as in some cases they have been when the circumstances or nature of the trade has rendered this course desirable.

On the other hand, it could not fail to be seen that as a mechanical arrangement of material it was an unsatisfactory one, especially where the double bottom extended through the fore and after holds, and not through the engine room, for the effect was to leave the midship part of the ship, where the strains were greatest, weaker than the parts before and abaft it, and the break in the continuity thus set up is one of the worst features that can exist in ship construction. On the other hand, when this objection is removed by the double bottom being extended all fore-and-aft, it is obvious that more iron is used than necessary for the strength of the vessel.

This fact has given rise to many proposals for embodying the tank arrangements more closely into the structure of the ship, but I am not aware that they were in many cases put into practice until quite recently. Mr. Reed, in his work on Shipbuilding, mentions the steamer *Sentinel*, built many years ago by Messrs. Palmer, of Jarrow, designed by Mr. Spencer, as having the longitudinal girders brought down on the outside plating, apparently without any transverse floor plates or brackets worked between them, but the system was not repeated. Again, in more recent times, 1874, the two screw steamers *Scio* and *Assyria* were built near Genoa, by Messrs. Westerman, to embody the same idea. The section of the bottom of the *Scio*, of 1,441 tons gross, is shown on Fig. 4. The floors are continuous in this case, and the side longitudinal is worked intercostally between them.

We next come to the *Fenton*, of 784 tons gross, built by Messrs. Austin and Hunter, for Mr. W. Milnes, in 1876, and which I have alluded to before. This is shown on Fig. 5. Here, as in the Chilian iron-clads, the frames extend through the longitudinals, instead of being in short pieces between them, as in the admiralty system, whereas the reverse bars are short. The frames and reverse frames are 21 inches apart, while solid plate floors and bracket floors are fitted alternately at every fourth frame, the longitudinals being further stiffened by vertical angles at every alternate frame. The vessel was a comparatively small one, and the structural as well as the local strength was deemed to be sufficient, and the vessel has been, so far as I am aware, perfectly successful.

When Mr. W. Denny took up the principle, he at first followed Mr. Martell's description of the *Fenton*, but the vessels he applied it to being about 2,000 tons gross register, and thus much larger and heavier than the

Fenton, he introduced additional brackets at every alternate frame to secure greater transverse and local strength. This was a decided improvement, and was introduced in the *Chilka* and *Chupra* class, built for the British India Steam Navigation Company in 1878. The same improvement was proposed, I believe, quite independently by Mr. J. Inglis, and I may say it had also been discussed by us at Lloyd's Register as a desirable step. In this form it has been applied very largely, but with variations in detail, to which I will allude presently.

In most of the vessels built since, bracket plates have been fitted to every alternate frame, with solid frames at the bulkheads, under the engines, at pump wells, and under thrust chocks, shaft bearers, &c.

In large vessels it is considered advisable that, in addition to the brackets, solid intercostal floors should be spaced at regular intervals throughout the vessel, at distances according to the size of the ship and the depth of the double bottom.

As a further modification of this system, many builders, and especially on the northeast coast, have adopted, in lieu of brackets, solid floors fitted at alternate frames between the longitudinal girders and lightened by holes, as shown on Fig. 6. In other cases, again, the solid floors are continuous from the middle line out to the edge of the tank, and the longitudinal girders are fitted intercostal between them. This latter, it is feared, would somewhat shock a pure disciple of the longitudinal system; but the fact is, that what with the outer and inner bottoms, the keel, middle-line and wing girders, there is abundance of longitudinal strength without aid from the other girders. Of course, this only applies to ships of moderate size, and would not be a proper system to encourage in ships of the largest size. Time, experience, and relative cost will, doubtless, determine which of these systems will ultimately prevail, or whether still further important modifications will be introduced. It has been suggested that, where the longitudinal strength will admit of it, the longitudinals as well as the transverse floors should be formed of brackets, but it is advisable that experience should be gained with the vessels now built and building before embarking further in that direction.

Before proceeding to discuss the details, I may, perhaps, be permitted to revert to a point of difference between the mercantile and the admiralty systems.

I have mentioned that in the former the frames extend through the girders, thus facilitating the construction, whereas in the latter the frames are in short pieces, and it is the reverse frame which is continuous. If we think for a moment how an iron-clad ship is loaded compared with a merchant ship, this might not appear to be without reason. An iron-clad has enormous weights of iron to carry on her sides, and heavy weights of armor and guns on the decks, which have to be transmitted through the sides and pillars, while the weights actually resting on the bottom are small compared with the upward buoyancy on it, so

that the general tendency is for the bottom to come up and to put the top in tension, except so far as the curvature of the bottom prevents it; whereas in a merchant ship, where the cargo rests on the bottom instead of being suspended on the sides, there is a greater tendency to sag and put the top in compression, and the outer frame and bottom in tension. Ashore, of course, in both cases the top would be put in tension.

In examining the system more in detail, it will be well perhaps to commence with the middle line. The most satisfactory arrangement at this part is in many respects a deep center through-plate, with side-bar keel and a flat plate on top, and this is the plan now generally adopted. With this plan, the frame can be rove through, or a short piece can be rove through to scarf it without much injury to the vertical plate. It has always been considered in the mercantile marine to be of great importance to have the vessel very rigid at the middle line, for it has to bear frequent heavy strains in docking and grounding, and if it had to depend for support upon its own movement bringing neighboring parts into play, there would be likelihood of its starting the rivets and creating trouble. To make this middle line equal in strength as a girder to the ordinary system with bar-keel and plate-keelson standing on the floors, it is found necessary to make the vertical plate considerably thicker than the other girders, with a wide plate of about equal thickness on top, and the butts should be double riveted at least through the main body of the vessel, and in large vessels it would be desirable to treble rivet the butts of the top plate.

A middle-line vertical center-plate with a bar-keel below makes a very unsatisfactory arrangement, because there is nothing to attach the lower edge of the vertical plate to between the bracket frames, a space of 4 feet, and even if it be bracketed at the intermediate frames, its edge is still loose over 2-feet spaces, creating an imperfect mechanical combination at a part like the middle line which needs exceptional rigidity. Next to the side-bar keel, the most suitable is the flat-plate keel, but there are points about it that are not free from objection.

I have shown on Fig. 7 a plan of such arrangement, and the first point which arises immediately it is examined is, whether the longitudinal double angle-irons on the keel-plate or the frames are to be cut to allow the other to pass through continuously. Unfortunately, while neither of them should be cut, one or other must be. The best plan is to cut the frame, and fit a piece of angle-iron frame on the other side of the bracket, scarfing the frame and turning up against the center-line plate, as shown on Fig. 8. In some cases the longitudinal angles are cut and the frames continued through, but it is an unsatisfactory mechanical arrangement for large heavy angles, such as are fitted at this part, to be cut into short pieces, and it is an important loss to the strength of the middle line considered as a girder.

The only serious objection to a side-bar keel is that, in case of damage, it leads to heavy expense in repairing, as so much work has to be

disturbed, and this is a point which naturally carries considerable weight with ship-owners.

Passing from the longitudinal aspect of the keel to a consideration of the transverse strength of the ship at the middle line, it will be seen in Fig. 9 that we have a girder of which the top is the middle-line flat-plate, and bottom the flat keel-plate, or the keel and garboard connections, the rivets attaching the bracket-plate to the vertical center-plate also assisting. Taking a length of 4 feet of this, and comparing it with the strength of the two floors with frames and reverse frames attached, which would come in this space, the transverse strength at the middle line is found to be much greater in the new system than in the old.

And here I may draw attention to the difference between the form of bracket at the middle line, in Figs. 5 and 9. Fig. 10 also shows another form of this bracket, which is now, perhaps, more common than either. The object sought in making this middle-line bracket in one piece each side, is to get more lateral support to the middle-line vertical plate at the center of its height. This plate is liable to more frequent and more severe strains than the other girders, from the keel striking the ground below, and from the thrust of the pillars above, and its rigidity against buckling throughout its depth is better insured in this way with comparatively little expense.

In some cases the space between the keel and first longitudinal girder is made up of a solid plate, lightened, as in Fig. 7, and the remaining spaces fitted with brackets of the usual form.

Passing next to the side or flange-plate of double bottom, we find several variations in the arrangement, depending chiefly upon whether the frames are cut at this part, or are run through. In either case, however, it is important that the side-plate of double bottoms should be of substantial depth, and should have brackets fitted on its outer side, in order to form an efficient combination between the bilge and the inner as well as the outer bottom. Where the frames are cut at this part, it is necessary to fit brackets inside and outside at every frame; but where the frames run through continuously, it is customary to fit brackets outside to the frames only which carry the bracket system, and not to the intermediate single frames.

I need not dwell on the different form of the brackets at this part, as so much depends upon the form of the body, the rise of floor, and the depth of the double bottom. I have spoken of the necessity to keep the side, or flange-plate, of the double bottom a substantial depth, and this applies not only to its depth amidships, but also to its depth forward and aft; and unless this is provided for in an early stage of the design, it becomes difficult afterwards to repair the omission without making the connection unsightly.

This is the only girder that curves inwards towards the middle line, and keeps square, or nearly so, to the vessel's side, the others being kept in longitudinal planes, and the outer one stopping when the side

girder gets sufficiently near to render its further continuance unnecessary. This is much simpler in construction than the admiralty plan of making all the longitudinals follow the edges of the plating, and has, I think, advantages in point of strength.

I will next consider the plating of the inner bottom, and this is a point on which far more differences of opinion have arisen than would at first sight have been imagined. And here I may perhaps mention that cellular construction has been lately subjected to far keener criticism than I ever remember before, for it has the talent of all the ship-building yards in the country turned upon it—to improve it, pick holes in it, simplify it, cheapen it, and, in fact, to perfect it by combining the maximum of efficiency with the minimum of cost. The consequence is, that now no cherished feature of the longitudinal system is sacred until it has been rigidly weighed and tested.

I spoke of the longitudinal girders being sometimes sacrificed to the transverse webs. A still greater heresy is to work the inner bottom transversely instead of longitudinally. Where this has been done the longitudinal girders have, of course, been made continuous.

Now I will briefly examine the reasons for and against plating the inner bottom transversely, and will explain why, in my opinion, it should be worked longitudinally.

The reasons for putting it transversely are, (1) that the riveting is more easily got at, and that it is cheaper; (2) that it increases the transverse strength; and (3) that there is sufficient longitudinal strength without working this plating longitudinally. The answer is, that the difference in cost is comparatively small, and that continuous lines of weakness are set up at every seam across the ship, whilst the transverse strength is not increased at all. It will be easily seen that the center line flat plate must be worked longitudinally, and consequently the transverse plating must all butt against it, or overlap it, so that there is what amounts to a longitudinal seam along the ship at this part—as pronounced a line of transverse weakness as if all the seams were longitudinal. Indeed, the other seams further towards the side of the tank are of far less importance to the transverse strength of the ship than this one. On the other hand, the transverse lines of weakness caused by single-riveted edges extending across the double bottom are unmitigated evils.

It is true the vessel might have plenty of longitudinal strength to withstand all the statical strains to which she might be subjected, but against dynamical strains, lines of weakness such as this across the ship are treacherous. A vessel striking the ground heavily—I mean a bank, not pointed rocks—instead of having her inner bottom to depend upon, would be liable to sheer one or other of these single-riveted transverse edges, even before the outer bottom gave way; for, forming as they do the top of the girder, they would be under the greatest tension, and would give way before the strength of the solid girders below them

could be fully developed. The fault is, indeed, similar in kind to that which would be involved in plating the vessel, or the decks, transversely, and is contrary to the best established traditions of ship-building.

The proposals to plate the inner bottom transversely have, no doubt, arisen from the fact that it was frequently done when the ballast-tanks were fitted on the floors, and were an addition to the structure; but the case is different when it forms, as in this system, an integral portion of the structure. For these reasons it is desirable that the butts of the plating of inner bottom should be carefully shifted similarly to those of the outer bottom, and the butts of the longitudinal girders should also, where they are continuous, be shifted with each other and with the plating butts. Manholes in the girders and inner bottom should also be considered like butts, and be properly shifted, and should not be more numerous or larger than is necessary to render the double bottom easily accessible.

I will next consider the position of the seams of the longitudinal inner bottom, and this is a point that I have often found overlooked, although it is one of much importance. I think it will be easy to show that these should be kept away from the longitudinal girders where the reverse bars are short between them, because the transverse strength is then not so entirely dependent upon rivet work. It is a rivet connection between the girder and brackets, and by having a solid plate of inner bottom on the girder, the connection is made a more complete one. On the other hand, when the seam is placed towards the middle between the girders, it has the unbroken reverse bars to support it, and this could be increased to any extent found necessary, by increasing the size of the reverse bars, or by strapping the joints of the brackets, as shown, shaded, in Fig. 10. And here it may be well to discriminate between the relative importance of the different seams of inner bottom as they relate to transverse strength.

The simplest illustration is that of a vessel docked when full of cargo, and somewhat similar conditions hold when a vessel strikes a bar or is to any serious extent resting on her keel. If we look to Fig. 9, we may take the cargo on each side of the middle line acting downwards through its center of gravity somewhat within the quarter breadth, and this, together with the hull itself, may be taken at about the position shown by the arrows W W, while the support of the ship is at the middle line in the direction of the arrow B. Now, the transverse strain on the vessel at the first seam out from the middle line is proportional to W $\times$ the distance *a* W, while that on the section in way of the seam next out is W $\times$ *b* W, and so on. Of course the bulkheads give great assistance against these strains, but about equally to all the different seams, and so leave those nearest the middle line still to bear the greatest strain.

In some calculations I made recently for vessels of a larger size than the one shown on Fig. 9, I found, taking a fixed length of ship with the bracket system of framing and with ordinary floors, that the trans-

verse strength at the first seam with the bracket system was but little greater than with the floors where the seam at *a* was single riveted; but when it was double riveted the strength of the bracket system was immediately increased upwards of 20 per cent. This, as you will readily see, arises from properly utilizing the inner bottom as a top flange for the girder—changing, in fact, an inefficient into an efficient flange. Another comparison was to put a solid lightened plate between the keel and first longitudinal girder, as shown on Fig. 7. That increased the transverse strength about 30 per cent., or rather more than the double riveting of the inner bottom seam. These figures show how important it is when we come to merchant ships of great size, where the number of transvere bulkheads is limited, to attend to the edges no less than the butts of the inner bottom. In reference to the comparison between the bracket system, shown on Figs. 5 and 10, and the plate system, Fig. 6, it will at once be seen that the advantage midway between the girders in point of strength lies with the plates, but this difference can easily be restored where deemed necessary by strapping the junction of the brackets, and it must therefore almost inevitably resolve itself into a question of economy of construction.

One other point that I must dwell upon, in reference to the arrangement of material in this system of double bottom, is the reverse frames. The question whether they should be continuous or intercostal is a moot point. Some builders are of opinion that the top angles of longitudinal girders should not be cut under any consideration, while others would not hesitate to cut these angles or the girders themselves to get more transverse strength. The reverse bars are generally fitted intercostal, but they are sometimes extended through the girders as in the admiralty system. Examining the arrangement a little more closely, I do not think there will be much difficulty in seeing how the advantages of both systems might be combined.

When the seams of inner bottom are placed between the girders, there cannot be much if anything gained by making the reverse bar which carries the brackets continuous, for it is abundantly strapped where cut at the girder by the rivets in the brackets on one flange, and the inner bottom on the other. It is not, therefore, worth while to cut the longitudinal angles for this one. The intermediate reverse bar is, however, different. It is necessary to the rigidity and efficiency of the inner bottom as an important part of the structure, but fitted alone in short lengths it does not make a good mechanical arrangement.

If in lieu of this angle fitted in short lengths below, it could be made continuous above the inner bottom, a stronger combination would be made; and it need not necessarily create any difficulty in the arrangement of the wood ceiling. Or even if instead of the angle a thick continuous strap were worked on top, the combination would, in my opinion, be better than at present, if the difficulty of keeping the tank top water-tight can be got over.

I would also mention as a matter of great importance the riveting of a system of construction like this I have been discussing. The rivets in the brackets, and in the angles which connect them to the outer and inner bottoms as well as to the girders, should be closely spaced to utilize the full strength of the system, and failing this, it is easy to make serious errors. Indeed, the necessity for extreme care in matters of detail prevails in this as in all new systems, and will continue to do so until it has become customary; and the larger the ship the greater becomes the danger if any important features are overlooked.

Closely associated with the movement in favor of cellular double bottoms in the mercantile marine is one for the substitution of deep web frames or partial bulkheads for hold beams. This favors stowage, and is likely, I think, to become very general. Like cellular constructions, it is a revival rather than a novelty, and we find Mr. Scott Russell has been over the ground before us. In the *Adelaide*, a steamer of 1,859 tons gross, built so early as 1852, there were eleven of these partial bulkheads, and I dare say he has fitted them to many other vessels that I have never heard of. They were also fitted in the *Fenton*, and are now frequently fitted in different forms by different builders. The plan which most commends itself to my mind is shown on the right-hand side of Fig. 9. The transverse webs are continuous, and from 12 to 16 feet apart, and the longitudinal ones intercostal, connected to them at the joints by diamond-straps as shown. It is an important point that these deep web frames should be attached to heavy beams at the deck, and well secured by strapping to the inner bottom, and that in way of them there should be solid plate frames in the double bottom. This is the present practice of Mr. Denny in large ships, and it is a very satisfactory arrangement.

The reason for making the transverse girders continuous at this part instead of the longitudinal ones is easily seen. It is, in the first place, near the height of the neutral axis where the longitudinal strains are not so severe as above and below it, and, in the next place, because it is easier to impart rigidity to the sides by spanning the short distance between the rigid iron decks and rigid bottom than by spanning longitudinally the whole length of a ship's hold. It may, of course, be urged that when the ship is on her side this becomes the top of the girder, but the argument is not a strong one, for a ship, owing to her greater breadth than depth, is usually stronger amidships longitudinally on her side than when upright.

I must now bring my remarks to a close, as they have already far exceeded the limits of time and space usually accorded. I have said nothing about the advantages which the cellular double bottom has over the ordinary one in accessibility for the purpose of examining, cleaning, and painting it, but these are self-evident. The questions of its cost, weight, and saving in tonnage are not points which properly come within the scope of this paper, and they are matters on which many builders pres-

ent will be able to speak with more authority than I can. I treat the matter from a purely technical and professional point of view, but I am sure information on the commercial aspect of the question will be no less welcome to ship-owners and others interested in the progress of shipping.

Many technical points I have had to omit, which are of great concern to my colleagues and myself, who have some degree of responsibility for the scantlings and arrangements of nearly every ship that has yet been built on this cellular principle of construction. The varieties in size of ship, in the depth of double bottom, in its extent, the different combinations which it is possible to make in the arrangement of girders and brackets, to say nothing of varieties in detail, have recently taxed our utmost attention, and the time is fast approaching when form and consistency will have to be given to the system, and it will have to be embodied in rules of a more or less definite description, but in the mean time it is important that the principles involved should be as fully and freely discussed as possible, and that all experience which may arise should be carefully collected and examined, and the whole system submitted to thorough and minute investigation upon lines somewhat similar to those which I have endeavored, but I fear very imperfectly, to trace out.

DISCUSSION.

Mr. J. SCOTT RUSSELL, F. R. S. (vice-president). Mr. Chairman, as I have been called the papa, or may I call it the grandpapa, of this longitudinal system, it is my duty at once to acknowledge all the faults I committed, and to take upon me all the failings which may be attributed to the longitudinal system. I wish, however, to apologize because at our meeting, either yesterday or the day before, it seems that I made some observations which were held to attribute to double bottoms some great faults, failings, or shortcomings which I certainly did not mean to attribute to them, and which I now entirely retract, if the words I used conveyed that meaning; and I only wish to do with regard to it, as I think it is wise to do in all such things, to take care that while you attribute to them their good qualities you should not attribute to them any more good qualities than those they really and intrinsically possess.

Now, although my favorite mode of building is called the longitudinal system, or called the cellular-bottomed system, if you please—because I will also take the responsibility of that, having built vessels with cellular bottoms for a long time, during which they were considered utterly heterodox—I must tell you that my favorite cellular bottom has one great fault, and it is this—that if you use those cellular bottoms in a small-sized ship, and if in a large-sized ship you use those cellular bottoms in any portion of the ship where they are too small to be freely

traversed by the painter, you ruin your ship. Now, when I say that for my favorite form I think I am doing my duty to you. I would not betray you for any consideration into adopting a cellular bottom under those difficult circumstances. Now, I wish to show you, in saying that to you, where I have had great difficulty in excluding a cellular bottom. You have heard that I introduced the cellular bottom on a large scale in the *Great Eastern*. I did so; but, as I have already told you, I made the cellular bottom with its cells so large that the painter could freely traverse them; and I beg to inform you that I think it an excellent rule both in ships and in boilers (and I have followed it myself) that you should never make any opening of such a size that a fellow in a fustian jacket could not go through it. Therefore, when I tell you that I have myself in a fustian jacket gone through every cell in the *Great Eastern* I show you that my opinion is not a theoretical one, but a practical one. In the same manner I may say that in the earlier days of boilers, I never made a boiler through which I had not gone; and I think I may say to you I never made a condenser through which I have not gone. I say, therefore, whenever your ship is so small that you cannot give the cells the necessary size, do as I did in the *Annette*, do not make it a double bottom at all; give it its longitudinal stringer, but do not close up the cells; and you see there that the cells are not closed up; but when you go further, then by all means close them. But there is another point. If you choose to make the double bottom such as that you can easily get into it, then by all means do as Mr. John has recommended—let there be a tank within the double bottom, and use that for ballast if it is convenient for you so to do. But I just wish to call your attention to one point with regard to the *Great Eastern*. It is quite true that she has a double bottom, but I call your attention to a fact not generally known, because I was opposed by my friend Mr. Brunel and everybody in this. In the *Great Eastern* I absolutely confined the double bottom to the center of the ship, and the reason was, as you will see, that the moment you go aft, and the moment you go forward from that, the shelving up of the ship would immediately prevent the double bottom from being accessible. But I did something which I now seriously recommend to your attention, as I do not think it has received much attention. I put in a water-tight iron deck at a sufficient height above the bottom, that it should answer the purpose of a double bottom, and at the same time, by proper iron-closed hatchways, should be accessible for cargo. In like manner I did in the after-part of the body—I did not do it in her. I do not know whether you are aware that in the after-part there is a division for the screw, and it is desirable to have a passage along, so that you can get along the screw, and attend to the journals, and all that. Therefore I should be wrong in saying I made an after-deck all the way abaft, because it is split into two; and although on both sides of the cells there are water-tight compartments, it is not absolutely a water-tight deck. Allow me to recommend to you as a

matter of great importance, that in any ship where you cannot conveniently get a cellular bottom you can secure many of the advantages of a cellular bottom, whether for ballast or anything else, by taking a deck, say 5 or 6 feet high, and by making that deck a water-tight deck, and making it, if you like to call it so, a cellular bottom—although it would not be in that case a cellular bottom—and making it so that it would be coveniently accessible for the stowage of goods and merchandise of all sorts. This deck is an important thing which I have to mention to you. I withdraw, therefore, any statement I may appear to have made, that there is in any case any disadvantage whatever in the double bottom, provided the double bottom is rendered easily accessible, so that you can depend upon its being kept in good order. There are hardly any other points on which I need touch. I need hardly say to you that this has been to me a most valuable and utterly unexpected communication. Not only that, but I must felicitate my friends at Lloyd's for having now absolutely come forward as the advocates of the advancement of a new system of structure. I attribute that very much to the fact that we have now educated and scientific men at Lloyd's; whereas I remember the time when they were not so educated and were not so scientific. I am now obliged to tell you, and I had hoped that Mr. John would have told you this fact, but he insinuated the fact, although he did not tell you, that at Lloyd's they black-balled all my ships for a period, I should think, of about twenty years; and if I had not had what is called a good reputation and gone to Lloyd's, and got Lloyd's on my personal responsibillty to class my ships A 1, and insure them as A 1, without being on the register, I should never have been able to build any of my ships at all. However, I stood out, I think, for thirty years, and at last it was found out that my ships were being insured at the same price in Lloyd's as their A 1 ships, and then after that they came in and said: "We will give you the A 1 class for your ships." I think my pet *Annette*, as late as 1861, was the first ship that was honored by being admitted in Lloyd's on any terms, and then, I think, she was classed A 1. However, the new generation of Lloyd's have come in, and I feel extremely proud that the young generation have come in, and have adopted a system which I am happy to inform you made the fortune of a half a dozen ship-owners before their ships were ever classed at Lloyd's. As a matter of dates, I think it right that I should tell you what the exact dates are at which I first introduced this longitudinal system, and what you may call the cellular system of construction. The first three iron vessels I built were very small ones, called the *Skiff*, the *Wave*, and the *Storm*. I built these in the year 1834, and my first lesson was this: I built the *Wave* on the ordinary principle, on the ordinary frames, and the ordinary skin, but with this difference, that she had a plus skin; and in the building of that vessel, I found out after experiment—because she was a vessel only 60 or 70 feet long, and 6 or 7 feet wide, and was built at a time

when there were no iron ships—that by straining this vessel, her great weakness—I built her as light as possible for the purpose for which she was built—was a weakness in longitudinal strength, and I found that her waste of material consisted in the frames of the ship. I then built, immediately after, the *Storm*, which was a much larger ship—a steamship—and I built her without a single frame from end to end. What I did was to build her entirely with transverse bulkheads, as if they were the frames, each transverse bulkhead being placed nearly as far from the other as the beam of the ship; and then I put longitudinals in, not as frames, and not as our present longitudinals, but in this way: I wanted a flush ship, and along every longitudinal joint I placed what you would call a T bar of iron, and this T bar of iron was the lap-joint, and what you would call the longitudinal stringer; and this vessel turned out the strongest vessel for her weight that I or anybody else had constructed. That was my experience; and, therefore, it was as early as 1834, when there were no iron ships, I think, at all, that I first became aware that the longitudinal system and the cellular system was the system of greatest strength, with the least weight and the least waste of materials. I may state that I had no opportunity for many years of building iron ships, because we engineers, in those days, were obliged to build ships that our owners would have, and not those we thought best; so that I continued getting wooden steamships for many years. But between the years 1844 and 1848 I was permitted to build one vessel for Ireland, and another vessel for Grimsby, near Hull; and those two vessels were absolutely on the longitudinal system through the whole of their middle body, but their ends were built with the old frame.

Now, allow me to explain to you the reason, and to apologize for the builders who did not introduce the longitudinal system so rapidly as I should have recommended them to do. The reason is absolutely this. I will take the Clyde. On the Clyde the men were so skillful in the building of iron ships with transverse frames, that really, I think, if I had lived on the Clyde, I should never have introduced the longitudinal system until as late as those have done who have now done it. And the reason is, because all the men, as I have said, were skilled, and all the men were instructed in building a ship, according to the lines, with iron frames; and so skilled were the men (I am talking of many years ago, and I hope it is so still) that an old friend of mine, who built iron ships there, told me that he never did anything but this: He put the lines of the ship—the cross-lines of the ship—on a great big board out in the building yard, and then all the men rushed to take their measures off those drawings; and "A" said, "You will take the three first frames;" and "B" said, "You will take the next three;" and "You the next three;" and so on; and every fellow settled what frames he was going to take, and all took their measures, and built their frames, and they were all paid by the number of frames they built. Now, I will put it to you,

where you have a large yard of men, all drilled so as thoroughly to understand their work, is it not awfully difficult to attempt to introduce a totally new system. Therefore, I apologize for the non-introduction, by my younger friends, of the system, by saying that they could not introduce it until they well re-educated their men, and I need not tell you that re-educating a generation of experienced men is a very difficult undertaking. And I am glad that my friends at Lloyd's are now undertaking to re-educate both the men and the masters in building longitudinal ships. I do not think that there is anything I can add to that but one word. Mr. John has very ably explained how he thinks the structure of those longitudinals could be best made, and I only wish to tell you that I think plain iron plates are almost better than any mechanism of any kind, and though the cutting out of the openings may be convenient and necessary for making the cells accessible, still I recommend you, wherever you can, to make all your longitudinals of solid plates. I think the strength of a solid iron plate is not yet quite understood; I think it is far greater than the strength of any combination of brackets, or anything; and I am a great adherent to the use of one solid iron plate as preferable to any ingenious mode of building up—with only this difference, that, where you do want accessibility, you could not do better than merely cut a man-hole in each of the plates which you are using; but I advise them to be cut in the transverse plates, and not in the longitudinal plates. Perhaps Mr. John does not recommend that. With regard to the *Warrior* class, and all of those, I must say I think it was the introduction of this system in the construction of the six ships of the *Warrior* class (with which our noble chairman and his predecessor had a great deal to do), which led the way to, and which has brought about what I may venture to call this revolution. Those are all the points on which I think it my duty to trouble you.

Mr. WILLIAM DENNY (member of Council). My lord, would you kindly permit me to say a word or two on this paper, because it is supplementary to some of Mr. John's information. There were several points that I thought of taking up with regard to this double-bottomed construction. But I shall defer entirely to the wish of our chairman to have the discussion kept within the limits prescribed by our rules. The points which I wish to take up with regard to this longitudinal double-bottom are points which Mr. John mentioned in his paper might be taken up by some of the ship-builders present. One of the points is the question of the economy of construction, and the other, the tonnage. Upon these two points you will doubtless desire to hear some information. With regard to the economy of construction, so far as weight is concerned, the weight of a steamer similar to Fig. 9, built in the way it is shown on the right hand of the diagram, is precisely the same as the one shown on the left-hand side of the diagram. That is proved, not merely by direct comparison between boats with a single bottom and with a double bottom, which we have built—and we have built a number—but

also by the scheduling of a large number of different types of steamers. Now, that goes to show that in using this double bottom, you get a stronger ship and more accessible, and a ship in which you do not produce any dead-weight. There is a further point with regard to economy—that is, with regard to the workmanship of these double bottoms. I need not tell you it is more expensive to build a ship with a double bottom than with a single bottom. But the real point that is favorable to this longitudinal system of construction is this—that when you have men trained to work by the new method, the method is as cheap, ton for ton weight consumed, as the method of building mercantile double bottom, as shown in Fig. 3. That I can assure you of, from practical experience. There is only one other point which I have to take up, which was referred to by Mr. John, and that is the question of tonnage. With regard to this question of tonnage, I will point out to you that there are two aspects of it. In one, as shown in Fig. 6, the inner bottom is straight from side to side; in the other, as in the case of Fig. 9, the right-hand part of the diagram, there is a perceptible rise of floor. In the case of Fig. 6, you would not gain much in the tonnage, because the bottom ordinates would be measured the whole breadth of the inner bottom; but in the case of Fig. 9 the rise of floor makes the bottom ordinate very small, and you gain very considerably. In a ship of 2,000 tons, gross measurement, the saving in gross tonnage was 120 tons, and the saving of net tonnage was 80 tons. I may also mention, with regard to this rise of floor, that it is an advisable thing to bring it from the center of the inner bottom into the wall, and it greatly increases the depth of shoulder to which Mr. John has referred, and which is of the greatest importance. I regret having taken up your time so long; but I wished to mention those two points as being points referred to by Mr. John, and points on which information was desired to be given.

Mr. WILLIAM HENRY WHITE (member of Council). My lord, permit me to refer to one point in particular (although I have notes of others which Mr. John has mentioned), with reference to ships of the Navy. I am quite aware of the difference between the requirements of the ships in the mercantile marine and in the Navy. I wish, as the time is so limited, just to refer to the passage on p. 97 in the paper, where Mr. John draws attention (I believe, referring to some calculations which I myself published) to some cases of ships in the Navy, where the strain on the bottom plating—the maximum strain—is only about a ton per square inch. I do not think it would be reckoned a fault that the strain should be so small, when it is remembered that those ships are built with excessively light hulls. But I desire to insist upon a difference between the facts as stated in the paper and the statement I should like to make upon the same facts. We have, in the armor-clad ships of the Navy, vessels in which it is of the highest importance to build the hulls light, in order to pile on the weights of armor, armaments, and equipments of all kinds. To do that, the problem we have to solve is this: We must have an

outer skin strong enough to resist local strains. We are compelled to have the double bottom for the purposes of water ballast, and to increase the safety; and we are compelled to have minute water-tight subdivisions of that double bottom, and of the hold of the ship. We start with those essential conditions. Then the problem is this: How to give sufficient stiffness to the skins of the ship, and to work into the hull of the ship the strength of the partitions put there for purposes of subdivision in such a way as to give us a light hull? We start, in fact, with quite special conditions, which Mr. John has fairly stated. But the result is this—that we get so much material put into the skins of our broad, full-girth ships, at the midship-section, that if we left the longitudinals out of account altogether in our calculations, we should have figures almost identical with those given; and if Mr. John, or anybody present, can give us a method of construction which will enable us to obtain sufficient local strength and less weight, we should be only too happy to adopt it. We have been struggling for years now to save on the weight of hull. There are many improvements in matters of detail which Mr. John has not personal knowledge of, because he has been for some years out of the admiralty service, which I did intend to mention, but I will not. I may say that all our efforts have been in the direction of simplifying construction. All our ideas have been directed to save weight of hull, and to economize the cost of construction; and, I think, in our recent vessels, as compared with the *Bellerophon*, which is the latest vessel mentioned in the paper, we have made a very material and important advancement.

Mr. HENRY H. WEST (member). My lord, may I be permitted to make one remark? I had several put down, but I will confine myself to one single point. At p. 10 of his paper, Mr. John makes a comparison between the tranverse strength at the middle line of the longitudinal system and of the ordinary system. Now, if we admit, as I think we must, that the construction at the middle line of the old "center-through-plate" was strong enough transversely, it is clear that we have got plenty of transverse strength in any of these longitudinal systems.

Mr. WILLIAM JOHN (member of council). I should like to offer one or two remarks. First, with reference to what fell from Mr. Scott Russell. I was very glad, indeed, to hear Mr. Scott Russell remove an impression created on my mind on Wednesday as to the double bottoms. I feared he was going with many others in condemning them on insufficient grounds. I mentioned that the *Annette* had been classed at Lloyd's, and Mr. Scott Russell has told us there was a history before that in connection with these vessels, and that the *Annette* was the first. I think he is a little mistaken in that, because, as a matter of fact, we have on Lloyd's register, as early as 1855—which is six years before the *Annette*—the *Baron Osy*, which Mr. Scott Russell built. Again, the *El Rey Jaymes I.* the same year, and in 1858 we have another of the same name, all before the *Annette;* so that, as a matter of fact, we must have been—

at least, our predecessors must have been—going on, assisting Mr. Scott Russell to the extent of their power, in this new system of construction over a good many years. I will only make one further remark. Mr. White has referred to the vessels of the admiralty, and has put his version of the figures very properly and rightly before you; and all I wished to do, and all I endeavored to do in my paper, was to draw correct inferences from the figures. That is, when you have the longitudinal system put into ships like these short iron-clads, or any other small ships, and you get results by calculation showing that these ships have very little longitudinal strain, it is no ground at all for lauding the longitudinal system; and the correct inference is that half of this material, or more, might be put in any other direction than longitudinally, if you get the local support out of it. In government ships, which have to be subdivided by bulkheads, I do not say for a moment that you do not get sufficient local strength by putting the material longitudinally instead of transversely. But what I wish to avoid is our arguing incorrectly from *formulæ* to practical effects; and I think Mr. White gave a good illustration of it when he said you might take out all these longitudinals, and still have all these ships showing by calculation as great strength as ordinary merchant ships. But what I wish to add is, you would also have very bad ships, unless you put the iron in in some other way.

Mr. WHITE. I did not mean taking out the longitudinals. I said, merely leaving them out of calculation.

Mr. JOHN. It comes to the same thing.

Mr. WHITE. No.

Mr. JOHN. So far as the argument goes, they are not wanted there for longitudinal strength, and the real basis of the question is—which is the best direction for affording local strength?

ON THE LEADING PHENOMENA OF THE WAVE-MAKING RESISTANCE OF SHIPS.

By R. E. Froude, Esq., *Associate.*

[Read at the twenty-second session of the Institution of Naval Architects, April 8, 1881; the Right Hon. the Earl of Ravensworth, president, in the chair.]

The purpose of this communication is to review the more salient points in the theory of wave-making resistance; and it will be convenient to take as a starting point the paper on "the effect of parallel middle body," which was read before this institution by the late Mr. Froude in the year 1877.

The experiments described in that paper were on a series of models, all having identical entrance and run, but different amounts of parallel middle body. The remarkable feature of the results was, that the introduction of the parallel middle body not only increased the skin friction, in virtue of the added area of skin, but affected the wave-making resistance also in virtue of the changed position of the after-body in reference to the wave system left by the bow; so that if the parallel middle body were gradually elongated the wave-making resistance would alternately decrease and increase as the after body was brought into favorable or unfavorable juxtaposition with the successive features of the wave system. This effect appears in Fig. 1 (Plate XVI) which is a reproduction of one of the illustrations to the paper referred to, and is a synopsis of the results of the experiments.

"This discovery," as says the paper, was "a most material addition to our conceptions of the manner of operation of wave-making resistance." The theory, as thus completed, may be briefly sketched as follows: The passage of the features of the ship through the fluid involves local excesses and defects of pressure due to "stream-line" action, which tend to cause corresponding local rises and depressions of surface, thus forming undulations resembling waves or portions of waves. When the speed of the ship approximates to that appropriate to the lengths of these waves, large waves are formed, and proportionately great wave-making resistance is encountered; there tends, therefore, to be a rapid increase of resistance as a certain speed is approached, a phenomenon which is of course the more definitely marked the more nearly uniform are the wave-lengths of the several portions of waves which the features of the ship tend to form. But the part played by the waves is not necessarily complete with their original formation, for they are attended by "echoes" or following waves, which may increase or diminish resistance, according to their position in reference to the succeeding features of the ship's form.

Thus developed, the theory was seen to explain the peculiar irregularities observed in curves of resistance, and to enjoin, in the first place, that the features of the ship's form should, as far as possible, be long in comparison to the natural waves which would have the same speed as the ship; and in the second, that the echoes of such waves as are nevertheless formed by the earlier features should, at the intended speed, place themselves favorably in reference to the succeeding features.

It was recognized by the paper in question that the theory as thus presented applies only to the resistance involved in the formation of the kind of waves which have crests transverse to the line of motion; and that an important part is played by the series of "diverging" waves, of which I will speak in more detail presently. These, as opposed to the "transverse waves" first referred to, have the special characteristics (1) that their echoes or following waves do not touch the ship's side, so that their part in the resistance is completed with their original formation; (2) that their increase of size with increase of speed is more gradual, their apparent size and the resistance caused by them being well marked at moderate speeds, at which the "transverse" wave element appears altogether absent.

The principal purpose of the present communication is to suggest steps towards filling up some important details of the theory as above sketched, and to give some instances of how the main points of the theory manifest themselves in actual cases.

Wave-making resistance, regarded in its actual effect as experienced by the ship, is of course simply the net fore-and-aft resultant of the fluid pressures acting normally on all parts of the surface of the vessel. If a body is at rest in undisturbed fluid, the pressures are throughout the true hydrostatic pressures, and the net fore-and-aft effect is zero. If the body is traveling through the fluid, but deep below the surface, the pressures are largely changed from the hydrostatic pressures, in virtue of "stream-line" action, but still the net fore-and-aft effect is zero (except in so far as the equality between the favoring and resisting pressures is vitiated by eddy-making). If the body is traveling at or close to the surface, the pressures are still further changed from the mere hydrostatic pressures in virtue of the formation of waves, and such additional difference as is thereby introduced between the sum of the fore-and-aft pressures is the wave-making resistance. The approach to the surface of the fluid, by admitting of wave formation, has changed the pressures, because the wave system is really a changed set of stream lines, and involves a correspondingly changed set of pressures, the disposition of streams and pressures being throughout such that there is a perfect correspondence between the force acting on every particle, and the motion thereby impressed upon it. It does not by any means follow that the change in the pressures is throughout in the direction of increase of resistance, *i. e.*, of increase in the sternward pressures and decrease in the forward pressures, for probably, in most cases, the

change of pressure is of the nature of a large forward force on some parts of the surface, and a larger sternward force on others, the wave-making resistance being the difference between these two. But it is, of course, an essential condition that this net sternward effect of the change of pressures should be such that the increase of energy consumed in propelling the body against the increase of resistance should equal the energy demanded by the maintenance of the wave system.

It will readily be understood that it would be fruitless to attempt to calculate, step by step, on first principles, even the approximate conformation of the combined wave and stream-line system that would attend the passage of any given body through fluid. But the converse process is comparatively easy, for we have sufficient knowledge of the character of the natural fluid disturbances proper to any given waves to form a tolerable idea of the nature of the enforced disturbances which would produce them. And if in this manner we learn what character of disturbance is implied by the waves which we see are actually made by ships, we obtain a clue to the solution of the question of how the passage of the several features of the ship's form through the water operates to produce the waves. A careful study of the actual wave systems produced is therefore an essential preliminary to the study of wave-making resistance.

In its main characteristics the wave system seems the same under all conditions. It seems invariably to consist partly of transverse and partly of diverging waves, and the angle of divergence of the latter does not vary greatly. The character of these two classes of waves is indicated in quasi-perspective in Fig. 2 (Plate XVI), which is also one of the illustrations of the 1877 paper on parallel middle body.

The transverse wave series consists of a row of parallel wave crests, square, or nearly so, to the line of motion, keeping pace with the ship, their length from crest to crest in the line of motion being about that proper to a deep-water wave traveling at the same speed as the ship. In a very long parallel-sided ship the crests of the transverse waves, formed by the bow, show for some distance against the side, successively diminishing in height as they spread sideways, and seemingly also recede slowly from the side in virtue of any slight angle of divergence. If the parallel side is so long that these crests have in this manner disappeared by the time the afterbody is reached, the stern is seen to leave a series of transverse waves of its own, of just the same character as that left by the bow; if, however, the straight side is not so long, these two series appear to coalesce into one.

The diverging waves present an instructive characteristic which escapes the observation of many persons whose attention is not specially called to it. If called upon to draw from memory a plan of the waves diverging from the bow of a vessel in motion, one would be inclined to show a long continuous diagonal wave-crest, reaching far away from

the ship's side, attended by perhaps one or two smaller crests nearly parallel to it.

To correct this erroneous conception, we must imagine the smaller crests abolished and the single main crest cut up into short ridges, each of these ridges being stepped back from the line of crest of its preceding neighbor, so that they stand in a row, *en échelon*. They taper each way from the middle towards the ends, and the adjoining taper ends overlap one another somewhat. At any one speed these short crests retain unaltered their positions relatively to the ship and to one another.

The crests broaden and flatten towards their outer ends (*i. e.*, the ends furthest from the ship), so that the crest line here becomes quite indefinite, and from the shortness and general irregularity of shape of these crests, it is difficult to measure with precision either their angle with the line of motion, or their wave-length normally to the crest line. The appearances, however, are perfectly consistent with what one would expect to find, namely, that the wave-length is that appropriate to a wave traveling at a speed equal to the component of the ship's speed taken normally to the crest line.

The general line of the series—*i. e.*, a line drawn in plan through the highest points of the successive individual crests—diverges from the line of motion at an angle large enough to place clear of the ship's side all the diverging waves formed by the bow, except the first, and sometimes the very innermost end of the second.

The principal diverging series is formed at the bow; but a series precisely similar in character, though generally less marked, is formed by the stern also, and the two series may be traced, distinct from one another, for some distance away from the ship.

The angle of divergence of the diverging waves, and the relative importance of the transverse and diverging series, varies of course in different ships, and in the same ship at different speeds; the general characteristics of the system, however, as above described, seem common to all forms of vessels under all circumstances. It is instructive to trace step by step the train of modifications whereby the wave system accompanying a large ship at ordinary full speed, or its equivalent, that accompanying a torpedo launch at low speed, changes into the system accompanying the same launch at her full speed. With this object a careful survey was made of the plan of the wave system accompanying a model of a torpedo-boat recently tried at Torquay at a large range of various speeds. At certain speeds also the longitudinal section of the level of the water surface in the wake was observed by measuring downwards from a carriage following the model on the level railway of the experiment tank. The results are shown in Figs. 3 and 4 (Plate XVII), the former showing the wave system made by an 83-foot launch at five speed ranging from nine to twenty-one knots, the latter showing in comparison on the same scale the systems made at a speed of eighteen

knots by the same 85-foot launch and by a ship of the same lines 333 feet long.

It will be seen that at the nine knot speed for the 83-foot launch (or the eighteen knot speed for the 333-foot ship) the wave system is precisely of the character observable in large ships at full speed, showing the familiar train of diverging waves at the bow and at the stern. As the speed is increased (or size decreased) both trains of diverging waves retain their character, but expand in scale relatively to the size of the ship, as they necessarily must (since the angle remains much the same), in order that their length may suit the speed; so that at twelve knots for the 83-foot boat the second diverging wave (*i. e.*, the first echo of the wave at the bow) is nearly opposite the stern; at fifteen knots more than half a length clear of the stern; and at twenty-one knots nearly two lengths clear. The point of departure of the first stern diverging wave drops astern as the speed increases, and it becomes more acute at its forward end; at the higher speeds it is recognizable as the peculiar kind of flat-topped cliff of water, wedge-shaped in plan, which always appears immediately astern of a high-speed launch, and which is now seen to be the representative of the first member of the ordinary stern-diverging wave series.

It is interesting to notice that the bow diverging waves made at eighteen knots by the 83-foot launch and by the 333-foot ship, as shown on Fig. 4 (Plate XVII), are, to all intents and purposes, identical in length and in relative position.

The transverse waves left in the wake were very low and flat at the high speeds, and were invisible to the eye (in the model) above the fifteen knots speed for the 83-foot boat, but they show plainly in the longitudinal section of the wake at the eighteen and twenty and a quarter knot speeds, and are found to have the correct length appropriate to the speed.

Having now examined the characteristics of wave systems actually generated by ships, we have next to consider to what extent the various component parts of it are responsible for resistance.

The energy embodied in a wave of any given dimensions is easily calculable, and it would not be difficult to calculate the total energy represented by any system of waves, or any parts of it. The question is not, however, what expenditure of energy must have been required to create the wave system, but what rate of consumption of energy is involved in its maintenance when created? The measure of this will be found to be simply the rate at which the wave system is essentially traveling away from the ship. True, in a wide sea the energy must eventually be absorbed in the internal friction of the wave motion; but we need not consider this, for the waste of energy of this kind in the immediate vicinity of the vessel must be infinitesimal, and as to the frictional waste in the rest of the wave system, it can only be operating in so far as a supply of energy to those parts of the wave system is be-

ing kept up from the parts nearer the vessel. It is the rate and manner of this supply, then, that has to be considered.

In reference to the diverging waves the solution seems easy. The wave as soon as formed immediately leaves the ship's side, and it is at once obvious that in running a given distance a ship must create a nearly equal length of new diverging wave on each side. The transverse waves, on the other hand, accompany the ship, and do not, therefore, at first sight seem capable of drawing away any energy, still less such large amounts of energy as are represented by the resistance which the experiments on parallel middle body proved to be due to them.

The explanation of this difficulty is also, as will be hereafter seen, the explanation of the curious skew arrangement of the crests of the diverging wave series. The explanation is to be found in the fact that a system of deep water waves does not travel as fast as the individual waves composing it. In fact, the energy represented by the wave motions is transmitted from particle to particle in the direction of travel of the wave by the mechanical conditions of wave motion; but this transmission is only effected at half the speed of the individual waves, so that although in reference to the particles of water the energy is being transmitted forwards, yet in reference to the waves it is in effect draining backwards from each wave into its successor. Consequently, if a limited group or series of waves is traveling across an otherwise still surface, the leading waves are continually dwindling and eventually disappearing, for want of the energy they are leaving behind. The waves in the middle of the series are also leaving energy behind, but receiving an equal amount from the leaders, and consequently retain their size unaltered. The hinder ones receive from in front more than they leave behind, and are thus growing in size, while behind them new ones crop up. This may be seen happening in the wave rings formed by dropping a stone into water. Now the wave system, as a whole, can only travel as fast as the energy is transmitted. The speed of the system, therefore, is exactly half that of the waves, so that in a wave system 100 yards long, the wave which is at one moment coming into existence as the hindermost crest, by the time it has run 100 yards will have become the central wave, and in another 100 yards of run will be disappearing at the leading end.

If, then, it were not for the supply of energy afforded by the passage of the ship's form through the water, the transverse waves close to her would be continually dwindling and disappearing, and by the time the ship had run a given distance the foremost end of the wave system would be left half that distance behind. The work, therefore, which she has to do in maintaining the system intact is equivalent to that of continually lengthening the system at the rate of half her own speed; and the consequent resistance (since resistance is energy divided by travel) is the energy of a single wave, divided by two wave lengths.

The proof of this proposition concerning deep water wave systems has

been drawn out by Prof. Osborne Reynolds in a paper read before the British Association in 1877, and also by Lord Rayleigh in his work on "The Theory of Sound."

I have said that this proposition is the explanation of the peculiar skew arrangement of the crests of the diverging series.

For let Fig. 5 (Plate XVIII) represent the arrangement of a system of diverging waves at a given instant of time. A B is parallel to the line of motion. C D is one of the crest lines, and intersects A B at the point of E. F and G are the terminations of the wave system, of which the crest in line C D forms a part at E. Ten seconds ago, say, when the ship was a distance E E_1 astern of her present position, the crest line C D was at C_1 D_1, intersecting A B at E_1, and the terminations of the system were at F_1 and G_1. During the ten seconds' interval from then to the present moment, the point E_1, in the crest C_1 D_1 moved to H, but since the wave system and the energy resident at any point in it can only move at half the speed of the wave, the energy that was resident in the particle at E_1 will have only traveled to I, and the terminations or boundaries of the system to J and K. The parallel lines through F J and G K must therefore show the present position of the boundaries of the system, and the crest C D and the others parallel to it (as LL, NN, OO, &c.) must terminate in those lines. This it will be at once seen gives the skew arrangement already described as the characteristic of the diverging wave series. The line joining the highest points of the successive crests will of course be parallel to the boundaries, and it will be seen that the angle of this line with the lines of the individual crests has its tangent equal to half that of the angle of the crest lines with the line of motion.

Regarding the diagram as showing the positions, in space, of the series of waves at a given instant of time, we see that during the ten seconds preceding that instant, the energy that was at E_1 has moved to I. So also, during the same time, the energy that was at every other point has moved a like distance in the same direction. If we now regard the diagram as moving along with the ship, instead of being stationary in space, it will represent the positions of the wave crests, not at one instant only, but continuously; the crest now at C D will therefore have been, ten seconds ago, not at C_1 D_1, but at C D as now, and the energy now at I will have been not at E_1, but at E. The energy, therefore, during the ten seconds in which the ship was traveling a distance equal to E_1 E, will have traveled along the system, and relatively to the ship, the distance E I, and the energy that was at all other points in the wave system will also have moved an equal distance in the same direction. If then we take some other time interval, choosing E E_1 of such length that E I equals the distance between the crests along the line E I, we may say that the ship has to make one new diverging wave

for every length equal to E E_1 that she travels. This gives as the expression for the resistance due to a given set of diverging waves—

$$R = \frac{E}{2 l \sin a},^*$$

$$\frac{H I}{l} = \left(\frac{\text{speed of diverging wave}}{\text{speed of ship}}\right)^2 = \sin^2 a;$$

$$\therefore H I = l \sin^2 a.$$

$$\text{Now } E E_1 = \frac{H E_1}{\sin a} = \frac{2 \times H I}{\sin a};$$

$$\therefore E E_1 = 2 l \sin a.$$

where—

R=resistance in terms of any force unit.

E=energy of a single wave in terms of the same force unit, and any distance unit.

l=length of wave due to linear speed of ship, in terms of the same distance unit.

a=angle of diverging wave crest with line of motion.

This, it should be noticed, by making $a=90°$ (when sin $a=1$), ought to give, and does give, the same value for wave-making resistance of the series, as has already been given for the transverse waves.

We now see, then, that the work a ship has to do in maintaining a wave system, whether of transverse or diverging waves, is in fact equivalent to adding to the system one new wave for every two wave lengths she travels. In this light the large resistance which we find to be incidental to the development of even a moderate train of waves, becomes comprehensible enough, and we are now in a position to see why the point of equality between the speed of the ship and the speed appropriate to the wave she tends to form is not signalized by such an emphatic exaggeration of wave height as one might at first sight expect. In the late Mr. Froude's lecture at the Royal Institution, quoted in the paper on "parallel middle body," the effect of the equality above referred to is compared to the synchronism with the natural period of a pendulum, of an alternating force applied to it; this analogy will be of use here. If a pendulum is nearly unresisted, we know that a very small alternating force, which produces no perceptible effect unless its period coincides almost exactly with that of the pendulum, will, if co-periodic with it, produce a large swing, so that the point of co-periodicity is very definitely marked by the result. But if the resistance of the pendulum is increased, the force required to produce a given swing in the co-periodic condition is increased, and the difference between this swing and that produced by the same force when not co-periodic becomes less marked. In fact, as the resistance increases, the importance of co-periodity diminishes. Now, to represent the wave-making of a ship, where, as we have seen, the energy of one new wave has to be

* If E I = crest distance along E I (as taken in text),

supplied for every two-wave lengths of travel, we must suppose the pendulum to be subject to a resistance which would absorb half of its energy in every complete vibration.

The analogy of the pendulum assists our conceptions of wave-making resistance in other ways. When the oscillation of a resisted pendulum is maintained by an alternating force, the alternating impulses must be given, not at the moment when the pendulum is at the ends of the swing, but while it is traveling in the direction in which the force acts; and if the forces are not discontinuous impulses, but change gradually so that their variations may be approximately represented by a harmonic diagram, the "phase" of this diagram of forces must anticipate that of the motion of the pendulum, the moment of maximum force in each direction being before the end of the swing of the pendulum in that direction. So that if we suppose stream-line pressures to be maintaining a wave, or waves, it is clear that the "phase" of the pressures must precede the wave "phase," so that the points where maximum and minimum pressure would have been if the wave were not allowed to form, would be forward of the crests and troughs of the waves which actually result. Applying this idea to the wave-making action of the bow of a ship with very long parallel side (see Fig. 6, Plate XVIII); supposing the line A A to represent the heights due to the stream-line pressures which would have place along the surface of the bow if the wave were not allowed to form (as, for instance, if the upper-works were removed and the surface of the water covered with ice), then the wave which would result would be not like B B B, a mere exaggeration of A A A, but rather like C C C, all the features being moved sternward.

The same reasoning applies to the action at the stern end, as indicated in Fig. 7 (Plate XVIII). Now, this sternward shift at both ends has a very important bearing on the question of resistance. We know from the stream-line theory that the stream-line pressures indicated by A A A (due to the supposed motion beneath ice) can exert no net fore-and-aft force upon the ship as a whole, consequently, the pressures which would be represented by a wave surface such as B B B, which is only an exaggeration of A A A, cannot do so either. But the sternward shift of the wave "phase" has the net effect of increasing the general pressure on the bow and diminishing that on the stern, and thus causes the resistance; without which resistance, as a means of extracting the necessary supply of energy from the ship, the resulting wave system could not live. Thus the difference between the curves A A A and C C C is at once the measure of the forces operating to cause the wave, and of their essential counterpart, the resistance of the ship.

The above reasoning applies to the independent wave-making operation of the two ends of the ship; let us next examine the operation on the stern of the train of transverse waves left by the bow.

We know, from the experiments on parallel middle body, that the po-

sition of the after body in reference to this train of waves affects the total amount of wave-making resistance, and that, according to this position, the total wave-making resistance may be either more or less than (or of course equal to) the sum of the wave-making resistances of the two ends acting independently. By what operation does this come about?

It is at first sight a reasonable view that the favoring or resisting effect is due merely to the general raising or lowering of the level of the water surface surrounding the after body, incidental to the presence there of one of the crests or troughs of the bow train of waves, the action of the after body to make waves on its own account going on meanwhile unimpeded. The bow train of waves in virtue of this favoring or resisting action are either restoring energy to or draining it from the ship, and their own energy must, of course, become correspondingly diminished or increased. It would seem, therefore, that the theoretically best possible result would be that in which the whole of the energy consumed in creating the bow train is re-absorbed at the stern,* thus annulling the resistance due to the formation of bow transverse waves, and leaving (in addition to that due to skin friction, &c., and diverging waves) only the formation of the stern transverse waves. The increase of resistance in the most unfavorable position of after body is due to a lowering of level, equal to the raising of level which produces the favoring result, so that the maximum possible increase ought to equal the maximum possible decrease. Therefore, according to this view, if we call the transverse wave-making resistance of each end=1, the total transverse wave-making resistance with very long parallel side would= 2, and the theoretical limits, so to speak, of goodness and badness of performance due to position of after body would be—

In best position =1
In worst position=3

This view, which recognizes the restoration of the energy of the residue of the bow-wave series as the limit of its effect on the after body, may be called the "restitution" view. This view is plausible; but if followed out in detail is found to involve the following paradox. The after body if coming to still water (as at the end of a long parallel side) makes its own wave and the resistance appropriate to it. When the train of waves left by the bow is introduced in the most advantageous position, *i. e.*, that in which the whole bow-wave energy is restored to the ship at the stern, the above view assumes that the after body does its own work, as before, unhindered by the presence of the bow-wave. This might be reasonable, if nothing meanwhile happened to the bow-wave series at the after body, in which case the resulting wave system

* This result could not, of course, be actually attained, because some of the energy must inevitably be lost by spreading sideway, before the stern is reached.

would be that ordinarily developed by the after body, added to that which came to it from the bow. But this cannot be the case, for since the bow-wave energy has been restored, the waves representing it must have disappeared, and the resulting wave system must be that proper to the after body alone. We therefore have the paradox that the passage of the after body through the water leaves precisely the same resulting wave system, whether "fed," so to speak, at its forward end with still water, or with water already in a state of wave motion.

To destroy or absorb the bow-wave system must require the action of forces derived somehow from the arrangement of stream-line pressures proper to the advance of the after body through the fluid, which arrangement of pressures is itself the source of the independent wave-making action of the after body. Since, then, both the absorption of the bow-wave and the formation of the stern-wave spring from the same source, it is impossible that the introduction of the former operation should not affect the latter. The bow-wave in being absorbed must do something to the stern-wave. It suggests itself as a reasonable hypothesis that this action is to arrest its formation—that, in fact, the function of the after body when advancing into water already in a certain state of wave motion, is to swallow up that wave instead of making any of its own. If so, the placing of the after body in the most favorable position in reference to the bow-wave series, has a double benefit: (1) the bow-waves restore their energy and are absorbed; and (2) in doing so, they prevent the expenditure of energy in making stern-waves. On this view the theoretically perfect result (*i. e.*, which would be obtainable with the best position of after body if the two ends of the ship were alike, and if the bow-wave series did not spread away sideways before reaching the after body) would be that there would be no transverse waves left at all, and no resistance due to their formation. Therefore if, as before, the united value of the transverse wave-making of the two ends acting independently = 2, the theoretical limits of goodness and badness of performance due to position of after body would be not 1 and 3, but 0 and 4.

The behavior of a pendulum affords an analogy which shows this supposition to be a rational one. Imagine a pendulum or plumb-bob fastened to a ring traveling along a rod at uniform speed. (See Fig. 8, Plate XVIII.) Let the rod be bent transversely in two places to S curves, as at A A and B B, the two straight parts at each end being in the same straight line, and the middle straight part, A B, parallel to them.

When the ring travels on the part A A B B, it will be first displaced sideways in one direction, will remain in this new position for a certain time, and be eventually replaced in its original position. The first displacement will get up a lateral swing in the pendulum (greater or less, according to the relation between the natural period of swing of the pendulum and the time occupied in the displacement), and this swing will continue unaltered as long as the ring remains on the middle straight

part. This swing represents the transverse wave series left by the bow, which shows unaltered all along the parallel side, except so far as it diminishes by spreading sideways. If the pendulum be artificially stilled before the second curve arrives, the replacement will likewise generate a swing which will remain unaltered throughout the succeeding straight part, and represent the train of independent transverse waves left by the stern in a vessel with very long parallel side.

But if, however, the pendulum remains swinging when the second curve arrives, the behavior of the pendulum on it, the magnitude of the resulting swing, and the total amount of energy expended in bringing the pendulum past the curves in the rod, will all depend entirely upon the point in its vibration which it has reached at the moment of commencing the second curve. In this operation we have the analogue of the effect of the presence of the bow-wave series upon the wave making of the after body, and the consequent dependence of the total resistance upon the position of the after body in reference to the train of waves.

What will be in all cases the behavior of the already swinging pendulum while traversing the second curve, and what will therefore be the resulting swing when it arrives on the final straight, seems at first sight a complicated question. In one case, however, it is very simple. It is perfectly clear that if the two curves, A A, B B, are exactly symmetrical with one another, and if the length of the middle straight is so chosen that the pendulum enters the second curve in the attitude and state of motion symmetrical to that in which it left the first, then the behavior of the pendulum throughout the journey over the second curve will be likewise symmetrical to its behavior on the first curve, and it must therefore leave the former, as it entered the latter, in a state of rest.

Here, then, in the action of the second curve to absorb the oscillation imparted by the first, its tendency to impart a swing on its own account being thereby defeated, we have a precise analogue of the suggested action of the after body, when most beneficially placed, to absorb the bow wave, and in so doing to forego making any wave of its own.

It is worth while pursuing the analogy of the pendulum further, and it may be observed that by substituting a moving rod and a continuous string of stationary pendulums for the stationary rod and single-moving pendulum, we may introduce the conception of resistance to longitudinal motion of the curved part of the rod, as the analogue of the resistance of the ship; and this resistance will be measured by the square of the amplitude of the swing of the pendulums left behind, just as the resistance of the ship, due to the formation of the transverse waves, is measured by the square of their height.

The case taken just now, in which the length of straight was such that the swing set up by the first curve was exactly quelled by the second, is really only a particular case of a very simple general propo-

sition which for present purposes may be stated thus: If A A A (in Fig. 9, Plate XVIII) represent the actual path of the pendulum-bob in reference to the rod B B B B, what would be the continuation of this path if the straight continued (this being, of course, precisely similar to A A A), and C C C the path which it would acquire in passing over the second curve if it entered it without swing; then the actual resulting path will be such that the ordinate to it, at a point any given longitudinal distance from the line D D, will equal the sum of the ordinates (at points the same distance from D D) to the two paths B B, C C, the ordinates being taken in each case from the middle lines of the vibrations, and accounted as positive in one direction and negative in the other. In other words, the resulting swing will be the path B B, set off not from a straight line but from C C C, or, equally, it will be C C C set off from B B.

In fact, the resulting swing is a compound of two others, viz, that which would have remained if the second curve had not existed, and that which the second curve would have itself created if the previous swing had not existed; and these two imaginary component swings being themselves simple harmonic vibrations of the same period, it follows from the laws of harmonics that the actual resulting swing is likewise a simple harmonic motion of the same period as the two components. It also follows that when the two components are simultaneous in the same direction, the resulting vibration will be at its largest, and will be the sum of the two, the energy being the square of that sum; and that when the components are simultaneous in opposite directions, the resultant will be at its smallest, and will be their difference, the energy being the square of that difference.

Applying these propositions to the wave-making of a ship, they amount to this, that the combined or resultant wave series left behind the ship will be such remainder of the bow-wave series as would have been there but for the after body (and which may be called the bow component), "superposed" upon what may be called the "natural" stern-wave series, *i. e.*, the series that would have been made by the after body if there had been no remainder of the bow-wave series (and which may be called the stern component). And, therefore, when the two sets of crests coincide, the resultant wave height will be greatest, and will equal the sum of the heights of the components; and when the crests of one component coincide with the troughs of the other, the resultant wave height will be smallest and will equal their difference. In any case the square of the height of the resultant series will represent the energy consumed in, and resistance due to, its formation. In the case already supposed, where the wave-making energy of both fore and after bodies = 1, and where the whole of that originally due to the fore body is supposed to remain to be dealt with in the after body, it is clear that, the two component wave systems being equal, the resultant wave height will in the best case be zero, and in the worst case will

be double that of either of the components, and involve four times the energy. Thus the energy expended in transverse wave-making will range from 0 to 4, as above anticipated (p. 124).

The total expenditure of energy in transverse wave-making may be described as (1) the amount represented in the lost portion of the bow-wave system (*i. e.*, that which has already gone away out of reach of the action of after body), added to (2) the amount represented in the combined wave system made by the after body acting on the remaining portion of the bow system. Of this second item, the degree of coincidence between the two imaginary component wave systems affords the measure; not, of course, that the two components are supposed to exist and act upon one another clear of the stern, and so regulate the height of the resultant system, but that their would-be coincidence is the criterion of what happens to one of the two when acted upon by the portion of the ship which would cause the other.

It has been pointed out (p. 124) that the theory as thus developed attributes a two-fold operation to the bow-wave series (or what remains of it), in its beneficial action on the after body, viz, (1) its own absorption, (2) the complete or partial frustration of the formation of the natural stern wave. In the case just now considered these two operations are equal. But it should be noticed that where, as must always be practically the case, only a part of the bow-wave series remains, the second of the two operations grows very much in relative importance. Suppose, for instance, the bow-wave series has dwindled to half its original height when it has reached the after body, then we may say:

a. Original height of bow-wave series = height of natural stern wave series say ..... = 1
b. Energy of either (as before) ..... = 1
c. Height of residue of bow-wave series ..... = $\frac{1}{2}$
d. Height of actual resultant stern wave in best case (*i. e.*, *a*—*c*) ..... = $1 - \frac{1}{2} = \frac{1}{2}$
e. Energy of ditto (*i. e.*, d^2) ..... = $(\frac{1}{2})^2 = \frac{1}{4}$
f. Energy of residue of bow-wave restored by its absortion (*i. e.*, c^2) .... = $(\frac{1}{2})^2 = \frac{1}{4}$
g. Energy saved by frustration of natural stern-wave (*i. e.*, *b*—*e*) ..... = $1 - \frac{1}{4} = \frac{3}{4}$

Or, again, if the bow-wave series had dwindled to one-third the height we should have—

a and *b*. As before ..... = 1
c. Height of residue of bow-wave series ..... = $\frac{1}{3}$
d. Height of actual resultant stern-wave in best case (*i. e.*, *a*—*c*) ..... = $1 - \frac{1}{3} = \frac{2}{3}$
e. Energy of ditto (*i. e.*, d^2) ..... = $(\frac{2}{3})^2 = \frac{4}{9}$
f. Energy of residue of bow-wave series, restored by its arbsorption (*i. e.*, c^2) ..... = $(\frac{1}{3})^2 = \frac{1}{9}$
g. Energy saved by frustration of natural stern wave (*i. e.*, *b*—*e*) ..... = $1 - \frac{4}{9} = \frac{5}{9}$

So that, in these two cases, out of the total effect of the two-fold operation of the bow-wave series already referred to, that attributable to the mere restoration of the energy of the residue of the bow wave accounts for only one-quarter in the first case and one-sixth in the second.

The following, however, is really a more correct way of regarding the

effect. Let A B be the height of the original bow and natural stern series respectively, and A^2, B^2 their energies. Let k A be the height of the residue of the bow-wave series, and $k^2 A^2$, consequently, its energy. Then the actual resultant stern-wave height in the best and worst position of after body will be $(B \pm k A)$ and its energy $(B \pm k A)^2$. Thus the total energy expended will be:

$A^2 - k^2 A^2$ (*i. e.*, irrecoverable portion of wave formed at bow).
$+(B^2 \pm 2 k AB + k^2 A^2$ (formed at stern).
$= A^2 + B^2 \pm 2 k A B.$

So that the term $k^2 A^2$, which represents the energy saved out of the bow-wave series, appears instead as part of the resistance of the stern wave, the actual favoring or unfavoring effect due to its presence being represented by the term $2 k$ A B, which is added to or deducted from the sum of the entire energies of the natural wave-makings of the two ends, represented by $A^2 + B^2$. As k diminishes the term $2 k$ A B increases relatively to $k^2 A^2$, which is the only amount taken account of by the *prima facie* "restitution" view.

Some results of the experiments on models with various lengths of parallel middle body throw a little practical light on the matter, and, so far as they go, they seem to corroborate the theory as above developed, and to negative the pure "restitution" view. These experiments, in addition to the measurement of the resistances of the models, with various lengths of parallel, which appear (reduced to ship figures) in Fig. 1 (Plate XVI), included observations of the longitudinal section of the level of the water surface in the wake of several of the shorter models of the series. Now, a comparison of the resistances of the shorter models certainly seems to indicate, and a comparison of the heights of the waves observed seems to postulate, a greater alternately favoring and resisting effect, or, in other words, a greater proportionate difference between the maximum and minimum amounts of transverse wave-making resistance, than the "restitution" view will account for, even on the supposition that when there is little or no parallel side the whole of the energy of the transverse waves made by the bow remains available for absorption in the after body.

Again, it has been above pointed out (p. 128) that the height of the waves made, and the amount of the resistance caused, will be at the maximum or minimum, according as the crests of the bow-wave series coincide with the crests or troughs of the natural stern-wave series. It follows also from the theory that in either of these two cases the crest of the resultant wave coincides with the crest of the larger of the two components, while if the crests of one series fall on the slopes of the other the resultant crest position will be a compromise between the crest positions of the components, though nearer, of course, to the larger of the two. Now the wave sections observed in the wake of the models at the speed corresponding to 13.15 knots for the ships are shown (in

ship figures) in Fig. 11 (Plate XIX), in a form which almost explains itself. They are shown above one another, the vertical interval between their base lines being proportional to the differences in length of parallel side, the points in each, representing the position of stern, being vertically over one another, so that the points representing the bow fall necessarily into a diagonal line. Diagonal lines parallel to this represent the position, as measured from the bow, of the successive wave crests of the bow-wave series as they show against the parallel side in the longer ships. (These positions are taken from careful observations made on the longer models.) These diagonal lines may be therefore said to represent the position in reference to the stern of the crests of the bow component of the resultant wave series. Unfortunately, there are no trustworthy independent data for fixing the crest position of the natural stern wave, *i. e.*, the stern component, but there can be little doubt that it must be at the point where the crest position of the bow component coincides with that of the resultant, namely, in the line L L...

It will be seen that the diagram shows pretty nearly what the theory prescribes, the maximum resistance and largest waves being about where the crest positions of the components coincide, and the minimum resistance and smallest waves where the crest of one falls in the trough of the other; further, we see that the resultant crest is not quite constant in position; but that where the crest positions of the components do not coincide it trends away slightly from the position appropriate to that of the stern component towards that of the bow component.

We have now considered the operations of transverse wave-making of the two ends of a ship, acting both independently and in combination. There is yet one more theoretical point to which I will refer, and this has reference to wave-making generally. Imagine a flexible sheet or curtain floating vertically in still water. If this water were invaded by a regular series of waves we should presently find the sheet, as the successive waves pass it, swayed from side to side and distorted so as to occupy alternately the two sides of a figure, such as A A, B B, in Fig. 10 (Plate XVIII). This figure has a definite character, and may be said to be the same for waves of all proportions and sizes, with the proviso that its vertical scale is proportional to the length and its transverse scale to the height of the waves to which it is appropriate.

If for the flexible curtain we substitute a strong screen, forcibly moved at every point, precisely as the curtain was swayed by the water, and in the same periodic time, it is clear that the screen will generate, in still water, forced waves precisely similar to those natural waves which previously swayed the curtain. Also that if the transverse scale of the figure through which the screen moves be varied (the character of the figure, however, as also its vertical scale and periodic time, being preserved unaltered), the height of wave generated will be propor-

tional to the transverse scale of the figure, or, in other words, to its area.

If we substitute a different figure of the same area for the screen motion, keeping the same periodic time, it will still make waves of the same length as before, but clearly not of the same height; because, although the aggregate displacement of water will be the same, the figure being of the same area, the displacements do not locally correspond to those proper to the wave when formed. So that a screen alternating with the same period through any figure of equal area but different character (such as a square or circle or ellipse or any irregular figure), or any figure even of the same character but differently proportioned vertical and transverse scales, will make smaller waves.

Let C C D D be a figure of the same character; but of transverse scale n times, and vertical scale $\frac{1}{n}$ those of the figure A A B B. It therefore has the same area. C C D D will then be the figure through which a flexible curtain would be caused to alternate by natural waves having length $\frac{1}{n}$ times and period $\frac{1}{\sqrt{n}}$ times, those to which the figure A A B B is appropriate. If then we substituted for this curtain also a screen forcibly alternated through the figure C C D D with period $\frac{1}{\sqrt{}}$ times that with which we have supposed the A A B B screen to be moving, then for similar reasons such screen so moving will make larger waves than a screen alternated through any other figure of equal area in the same periodic time. We see, then, that a screen alternating through a deep figure at a slow period and making the long waves appropriate to its depth will make larger waves and demand a larger supply of energy to keep it moving than one alternating through a shallow figure of the same area at the same slow period and making equally long waves; while, on the other hand, a screen alternating through a shallow figure at a quick period and making short waves will make larger waves, and therefore consume more energy, than one moving through a deep figure of equal area at the same quick period, and making equally short waves.

It is a reasonable inference from this that the wave-making features of a ship will operate more effectively to make short waves if their displacement is disposed broadwise rather than deepwise, and more effectively to make long waves if it be disposed deepwise rather than broadwise. Now the diverging waves being necessarily much shorter than the transverse waves, we see that flaring out the end sections of a ship, or increasing the ratio of breadth to depth, will, *cæteris paribus*, tend to increase the resistance due to diverging waves and diminish that due to transverse waves, while the giving "U" sections or increasing ratio of depth to breadth will have the opposite effect. These inferences are visibly corroborated by the appearance of the wave systems caused in the cases referred to. Again, it is worth noticing that the experiments at Torquay have shown that as a rule moderately U-shaped

sections are good for the fore body, and comparatively V-shaped sections for the after body. This would seem to show that in the wave-making tendency of after body the diverging wave element is less formidable than in that of the fore body, and this inference corresponds with the fact that the stern diverging wave series is visibly less marked than that of the bow.

I now proceed to give some practical instances of the operation of the causes we have been considering.

Fig. 12 (Plate. XX) shows resistance curves of long merchant ships of the usual type, models of which have been tried at Torquay. For convenience of comparison, the ships are here brought to a uniform length of 400 feet. The other dimensions, displacements, &c., are tabulated on Fig. 12, and their load water lines, and a water line 10 feet below the L. W. L., for a distance of 120 feet from each end, are shown together for comparison in Fig. 13 (Plate XXI).

To enable the features of the resistance curves to appear more distinctly the resistances are shown in the form of curves of "residuary" resistance (that is to say, total resistance, minus skin friction). They include higher speeds than the vessels could attain, and for one of the ships at a lighter draught a curve is shown (on a different scale) up to 46 knots, at which speed the ship may be considered as corresponding to a torpedo boat of 100 feet long traveling at 23 knots.

I have introduced these results into this paper chiefly in order to exhibit the remarkable "humps" and "hollows" in the resistance curves, extending in regular succession as we advance up the scale of speed even to torpedo-boat speeds.

These features begin to be visible at about 12 knots speed, and are very strongly marked at 16 and 18 knots. They occur at approximately the same speeds in each of the three ships and at each draft in the same ship. The speeds at which they occur are, however, rather higher, and the features themselves are more pronounced, the deeper the draught. The combination of these two characteristics results in a curious difference between the effect of change of draught on resistance at different speeds. It will be found that all the above characteristics accord well with the theory as it has been presented in the earlier part of this paper.

In the paper on "parallel middle body" it was pointed out that the operation of the bow train of waves upon the after body must not only produce at constant speed alternate excesses and defects of wave-making resistance compared to its mean value as length of middle body is gradually changed, but, where there is considerable length of parallel middle body, must also, if length of middle body is constant and speed is varied, cause similar alternate excesses and defects of resistance compared to its mean rate of growth, and thus cause "humps" and "hollows" in the resistance curve. It was further surmised that these phenomena would manifest themselves in ordinary ships with long mid-

dle bodies, in spite of the fact that the side is generally rounded gently rather than absolutely straight; and this we now see to be the case. It will be readily seen that the theory must necessarily involve a relation between the speeds at which the successive "humps" and "hollows" occur. This works out as follows:

From the reasoning used above in connection with Figs. 6 and 7 (Plate XVIII) it may be concluded that the principal wave-initiating operation of the bow of a ship is bestowed on the crest and back slope of the incipient wave, the succeeding trough and other features in succession behind it following naturally as parts of a wave system already formed. The same may be said of the wave-initiating operations of the stern, substituting, however, the words "trough and forward slope" and "succeeding crest" for "crest and back slope" and "succeeding trough."

As speed is increased, the "succeeding trough" and "succeeding crest" referred to will both move sternwards somewhat; but, probably, by an approximately equal amount; so that if the position ot the "succeeding trough" at the bow be A, and those of the next crest, trough, crest, &c., be B, C, D, &c., and if the position of the "succeeding crest" at the stern be A_1, and those of the next trough, crest, trough, &c., B_1, C_1, D_1, &c., the distances A A_1, B B_1, C C_1, D D_1, &c., which are of course all equal to one another, remain approximately constant in any given ship, whatever the speed. We may call this distance the "wave-system distance." Now, remembering that, according to theory, the wave-making resistance of the after body is at its maximum when the crests of the independent bow and stern-wave systems coincide, and at its minimum when the crest of one coincides with a trough of the other, we should expect to get successive "humps" in the resistance curve (due to coincidence of crest with crest), at the speeds at which the "wave-making distance" $= \frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}, 3\frac{1}{2}$, &c., complete wave lengths, and "hollows" (due to coincidence of crest with trough) at the speeds at which the "wave-making distance" $= 1, 2, 3, 4$, &c., complete wave lengths. And since the length of a wave varies as the square of the speed, the successive "hump" speeds will be—

$$\frac{C,}{\sqrt{5}} \quad \frac{C,}{\sqrt{1.5}} \quad \frac{C,}{\sqrt{2.5}} \quad \frac{C,}{\sqrt{3.5}} \text{ &c.,}$$

and the successive "hollow" speeds,

$$C, \quad \frac{C,}{\sqrt{2}} \quad \frac{C,}{\sqrt{3}} \quad \frac{C,}{\sqrt{4}} \text{ &c.,}$$

the value of the constant C being dependent on what we have called the "wave-making distance."

This reasoning is remarkably well verified in the curves on Fig. 12 (Plate XX). The speeds 13.7 knots, 16.2 knots, 20.9 knots, and 36 knots may be fairly taken as the successive "hump" speeds, and the speeds 12.8 knots, 14.8 knots, 18.1 knots, and 25.6 knots, as the successive

"hollow" speeds; and it may be seen that these eight speeds are severally proportional to the values

$$\frac{1}{\sqrt{3.5}} \quad \frac{1}{\sqrt{2.5}} \quad \frac{1}{\sqrt{1.5}} \quad \frac{1}{\sqrt{5}} \quad \frac{1}{\sqrt{4}} \quad \frac{1}{\sqrt{3}} \quad \frac{1}{\sqrt{2}} \quad \text{I}$$

The fact already noticed, that the deeper the draught the higher are the speeds at which the "humps" and "hollows" occur, explains itself on the hypothesis that deepening brings more into play the fuller upper lines of the bow and stern, and thus by moving the bow-wave system forwards and the stern-wave system sternwards, increases what we have called the "wave system distance," and thereby increases the speed necessary to bring about a given coincidence between the independent wave systems of the ends.

Again, the "humps" and "hollows" in the curve of ship C are at rather lower speeds than in the other two ships. This seems attributable to her greater sharpness and hollowness of extreme bow, having the effect of diminishing the "wave system distance."

Lastly, the fact that these hump features are more pronounced, the deeper the draught, is a witness that the transverse wave making element, which causes these features, is increased by deepening of draught; and thus instances the greater potency of depth of form for transverse wave making, referred to above (p.).

DISCUSSION.

Mr. WHITBREAD. My lord, may I ask Mr. Froude whether we could do away with the waves at the head of a vessel altogether, and fill up the vacuum at the stern so as to do away with the after waves, or dead water, or whatever it is termed? Would it not materially aid the vessel in her passage through the water if that wave in front and behind were removed?

Mr. FROUDE. Certainly, if the ends of the ship could be moved so as not to make waves, it would materially aid the passage of the ship through the water. The question is, how to do that?

Mr. DENNY. I rise only for the purpose of expressing on behalf of those mercantile men who are owners of ships the great satisfaction this paper has given us. When I had the pleasure of listening to the paper referred to in it, read by Mr. Froude's late father, on the wave-making resistance due to additional lengths of middle body in ships, I thought at that time it was hardly possible the subject could have been carried further, or that it could have been more completely exhausted. But the paper which has been read to us to-day has shown us that the subject can be carried further, and that it can be still further exhausted; and we have reason to congratulate ourselves that although in the loss of the late Mr. Froude we suffered a great loss, and one we all deeply re-

gret, we have not suffered a loss made irreparable to us; but that in the place of the father we have the son, with all the promise which every one who studies naval architecture and desires its progress is glad to see. There is a point in which Mr. Froude resembles his father, which must be extremely grateful to builders in the merchant service. The late Mr. Froude took a deep interest in mercantile ship-building. He took a very deep interest in the question of the resistance of ships built for the mercantile marine. He experimented upon these, and not only experimented, but at great pains he helped to lay bare many of the fallacies which we now see exposed to view. I mean those fallacies in regard to extremely narrow ships. I think it is surprising that in so short a time seed of so good a quality should have produced such good fruit as the late Mr. Froude's labors have done in this way. In fact, the truth is that at this moment, so far as we in the mercantile marine think about speeds, we think in the thoughts and speak in the words of the late Mr. Froude, and we have comparatively no power to think beyond that. In the results Mr. Froude has placed before us to-day he has spoken of a ship 400 feet in length with a speed of 46 knots per hour. This, I think, is a matter worthy of note. If we have seen small vessels of 100 feet long brought up from a speed of, we will say, nine or ten knots, which launches used to go at, to a speed of 23 knots, is there not a hope, gentlemen, that we may see vessels 400 feet long brought up to the equally appropriate speed of 46 knots? I do not think, gentlemen, you will see that rapidly done. I think there is great work before us before it will be possible to do that, but I think that Mr. Froude having given us this indication, we should not allow it to drop out of our minds easily, but feel that we have a hope before us worthy of attainment in this diagram showing 46 knots speed.

Mr. PURVIS. My lord, one of the many advantages connected with this paper is the value that is shown to attach to experiments with models. I think the notion must be new to most in this room that four several trains of waves accompany a vessel, namely, one transverse series started by the bow, one transverse series started by the stern, one diverging series started by the bow, and one diverging series started by the stern. This must be new from the mere fact that the existance of these cannot be seen in the case of a ship, owing to the disturbed state of the water; from one cause or another some of the phenomena are sure to be masked, and not all appear. But Mr. Froude has brought before us in his paper far more than that. He has not only found out the existence of these series of waves, but he has found out the effect that two of them have in their mutual action upon the resistence of the ship. I think we shall all agree with Mr. Denny in what he has said, and feel thankful for the philosophic way in which Mr. Froude is conducting the experiments under his charge, and we look forward to more results in the future, perhaps of a more practical nature than those which he has been able to put before us to-day.

Mr. BARNABY. My lord, I have heard with very great pleasure the remarks made by Mr. Denny as being the point of view of the advanced modern ship-builder as to the value of the work which has been done at Torquay, and I would also say that, on the other hand, the Torquay establishment benefits by the information placed at its disposal by those gentlemen who are engaged in producing the long merchant ships which have been spoken of here to-day. The models which have been experimented on there, are models of ships which were placed at the service of Mr. Froude by ship-owners who are building ships at this moment for high Atlantic speeds. The names are not given here, but they are really the models of ships which are being built which are described in this paper, and the information gathered with regard to those forms has been communicated to the owners and the builders of those ships. I am quite sure I may say for Mr. Froude, as I say for myself very heartily, that we shall only be too delighted, so long as the admiralty establishment at Torquay shall be the only one in England which is capable of doing that work, to have placed at our disposal information of that kind for the purpose of making experiments such as those which Mr. Froude has so ably described this morning. We can only hope that the efforts of Mr. Denny, and those who are engaged with him, to establish similar places in other parts of England, may be successful; we heartily hope they may be. One point which is very interesting to me as the representative of those who are concerned in the building of ships of war is the point which has been referred to by Mr. Denny, namely, the advantages which are, apparently, to be secured by having greater beam given to the ships. I never attempt to look into the future regarding ships of war, costing such large sums as those ships do, in order to discover, if I can, what the future has to show, what the guns are going to be, what the armor is going to be, what the size and the cost of those ships are going to be, without falling back upon this reflection, that in the end we shall have to look very largely indeed to the mercantile shipping of the world to protect and look after its own interests. One of the difficulties in the consideration of that question is the extreme narrowness of the merchant ship. We know perfectly well that we cannot ask the mercantile ship-builders and ship-owners to put their machinery below the water-line. They will have engines extending a very long way above the water. We never can look upon machinery arranged in that way, in such ships as we see crossing the Atlantic, without shuddering at the reflection that if they were exposed to shot or shell fire that machinery would very speedily, in all probability, receive serious injury—that, in fact, it is necessary to give to it some protection. Protection cannot be given to that machinery above the water unless there is considerable beam to the ship. The ships as they are now built are too narrow for the machinery to receive that amount of protection which it ought to receive if the ships are ever to perform the service which I cannot help regarding as the service which they will have to perform in

the future. There is another point to which attention has been called, and that is the possibility of having these very high speeds. My friend who is sitting here on my left, and who was the first to show us the remarkable phenomenon of getting boats to rise up out of the water and travel along at amazing speed (Mr. Thornycroft), has, I know, devoted his attention to the question whether it may or may not be possible to make big ships do the same thing. I think he came to the conclusion that he would want tremendous horse-power in his engines, and that there did not seem to be any way at present in which to get that. One very encouraging thing in regard to that is to see how those curves as you get to those high speeds flatten out and run away. It may be gratifying to you to know that it is not therefore an impossibility, and that we may be talking this morning about a thing which may really happen before very many years are over our heads. Perhaps while your lordship is president of the Institution we shall have sea-going ships doing what Mr. Thornycroft has shown us can be done with boats. Let us hope that that may be so.

Captain CURTIS, R. N. Mr. Froude has suggested that the U-form for the entrance or mid-section and the V-form for the run is desirable for speed. In 1853 I was on the coast of Africa, and as we were sailing along I always found that a porpoise went faster than the ship, at whatever speed the latter was going, and crossed her bows. It occurred to me that I might make use of the formation of the porpoise. I took a pair of compasses and took the lines. In 1854 I transferred that to paper, and the result was very nearly the same as the section of a salmon, and also of a mackerel. I would call your attention to the lower diagram, in which I will just refer to the black line about two-fifths from the bow. For instance, if a vessel was about 30 inches long, one-half the length of a porpoise, her extreme beam would be at 12 inches from the bow; it would be 7.5 inches beam at 12 inches from bow. I may state that the midship section at two-fifths is a semicircle, and every section of that vessel is a segment of the same circle. Mr. Froude will correct me if I am wrong, but I think that is the form that he requires in order that no other part of the ship except the bow should create a wave; and the run or after body should absorb the bow wave as far as possible. The bow is always creating a wave. I think that is all I have to say. It bears out the statement that the extreme beam should be at two-fifths of the length: Beaufoy's experience.

Mr. BILES. My lord, with respect to the remarks of Captain Curtis, I think if we were designing ships to go under the water instead of to go on the surface of the water, it would be very valuable to have the results of observations made upon fish laid before this institution, but as the experiments of Mr. Froude have been made upon models which run upon the surface of the water such observations seem hardly relevant to the question. This question of wave-making resistance is part of one great question, and I do think it is one that has not received the

attention that it should have. We have had several papers during the present meeting, and in the last two meetings, upon the question of stability. Now, I think, my lord, that the question of stability is one that we may certainly say is well in hand. We know how to make ships safe, but with respect to this question of wave resistance there is so much yet to be learned that we may say that we know comparatively nothing about it. It is, therefore, one that this Institution should devote its energies to, because the interests that are involved in this question of wave resistance are so great and so wide that really the results to be reaped from such an investigation would repay an almost infinite amount of labor and outlay. I think that this question has not been brought so prominently before this Institution as it should have been. Mr. Froude stands, as Mr. Denny has pointed out, almost alone in his investigations upon this question; and it is a great thing, and a thing which this Institution should congratulate itself upon, that the ship-builders—some of the leading ship-builders at any rate—are following on in the lines of Mr. Froude, and endeavoring to supplement the information which he is giving by results of actual experiments—actual trials I should say—with big ships. The peculiarities shown there (pointing to diagram) in those curves of resistance do not present themselves upon the speed curves obtained at progressive mile trials, and I think the reason of that is partly that speeds which have been obtained in vessels have not been so high as shown there, and partly from the fact that a sufficient number of speeds has not been taken in order to determine them as closely as they are determined there. I suppose it would be impossible to determine those curves unless speeds were taken at half knots apart. But I think it would be possible, without going into the time that would be required, to carry out the speeds at every half knot of the measured mile, to determine those curves a little more accurately than is done on the mile. And it would be done in this way: If a speed curve were plotted in the usual way in which it is in the results of ordinary progressive mile trials, and the revolution curve were then placed alongside it, it would be easy afterwards, while the champagne was being drunk, and the pleasure party was going on, as is the case during these trials, to take a series of observations merely by taking revolutions and indicator diagrams, and plotting those on the basis of revolution, and not speed, filling in the curve in much greater detail than it is filled in at present. I think that is a point which is worthy of the notice of those ship-builders who go to the trouble and expense of carrying on progressive mile trials. Mr. Froude has spoken with reference to the diverging waves, and has said that it is somewhat difficult to notice those waves at this point, but I had occasion lately to notice a series of waves in a paddle-boat. I have the permission of Mr. Thompson to say that we shall be trying a paddle-boat again in the course of a week or two at a high speed, and he will be very happy to carry out any experiment which Mr. Froude may indicate, with a view to observ-

ing the large diverging waves which are shown in the course of these paddle-boat experiments. The investigation which Mr. Froude has laid before us of the way in which the waves die out is an exceedingly elegant one, and I think it is one for which this Institution cannot thank him too highly.

Mr. W. H. WHITE. Mr. Barnaby has spoken of the hopefulness of the future as regards the attainment in full-sized ships of very high speeds. I have taken the trouble, while Mr. Biles has been speaking, to work out the horse-power corresponding to the 46-knot speed for a vessel of 5,400 tons. I have the authority of Mr. Froude for saying that if we take the residuary resistance only, and leave out the surface friction, we shall require the modest indicated horse-power of about 130,000. Of course, I am quite at one with Mr. Barnaby about the hopefulness. I simply want to indicate the magnitude of the undertaking. I quite agree with Mr. Barnaby there is hope for certain purposes. But it is a question for the engineers chiefly. How can they give us the power, and how can we use the power? For it will be wanted, so far as I can judge. Mr. Thornycroft, or Mr. Yarrow, or any body else who is skilled in engineering, will have to discover how about 130,000 horse-power can be usefully applied to a vessel of that draught—we need not be particular, because when we get up to that power, or a little more, we can begin to consider the question. But, at present, all that we can do is to look at it, as Mr. Barnaby says, hopefully, always remembering that the corresponding problem has been solved in a smaller vessel. Now, that brings me to what I want to say. Mr. Barnaby had in his mind, I know, because it is a fact with which he is perfectly familiar, that when these very high speeds are reached, the increase of power is just as the speed; that is to say, the curve of resistance turns into a straight line. In the torpedo boat that condition is reached. When Mr. Bramwell read his paper here, I analyzed the curve of the *Miranda*. I did not quite believe it; I thought there must have been some mistake. There were acknowledged difficulties in that case in measuring the power. I doubted the curve simply on that account. Now we know, as a matter of fact, that if those speeds can be reached where, as Mr. Barnaby says, the vessel comes onto the top of the water, the expenditure of power for higher speeds increases at a moderate rate. But before that is done we shall want a small revolution in our engineering. I would join in the thanks which have been given to Mr. Froude for his great labor, not merely in the preparation of this paper, because that does not represent it at all, but in the experiments that went before. When we look at these beautiful drawings, and we know, as I do personally, that for every indication on those drawings a series of observations and check observations has to be made—I do not know how many journeys must be performed up and down the tank to make sure that they are right—we must be very grateful to any gentleman who will undertake the extreme labor and the careful ob-

servation necessary to produce diagrams like these. I can never look at these diagrams without thinking of the changed conditions since Professor Rankine first began to conduct his analytical investigations into this question of resistance and wave-making. Not long ago I had occasion to go through that part of "ship-building, theoretical and practical," where the accounts of his investigations are given, and it is singular to notice how fully he appreciated the existence of those diverging waves; but I do not think he dreamt of the existence of transverse waves, so far as I have been able to trace his reasoning. If Professor Rankine, with his wonderful power of analysis, had had such facts as these to work upon, we cannot help seeing that his labors would have been productive of much greater influence on practice. As a matter of fact he could only make observations on ships, and Mr. Inglis conducted most of the observations that were made in connection with these diverging waves. You will find the facts stated in our transactions in connection with Professor Rankine's paper on virtual depth. Now, in contrast to that analytical method—that draught upon the imagination which Professor Rankine and those who worked in the early days had so largely to make—we have here introduced well-established facts which Mr. Froude has shown how to analyze. We first get the facts, and then we attempt to account for them and to make use of them. The change of conditions, gentlemen, it seems to me, is enormous; and as speeds go on, and we get beyond what precedent can teach, and have to work under entirely novel conditions, I cannot help thinking that this great system of model experiments which Mr. Froude has grafted upon Professor Rankine's stream-line theory, is the thing to help us more than anything else.

Mr. JAMES HAMILTON, jr. My lord, I desire to make a single observation with reference to diagrams Nos. 3 and 4. Mr. Froude has pointed out that diagram No. 4 shows the same wave formation for a very small steam launch as for a large ship. I think that is what one would expect if the forms are similar and if they are driven at corresponding speeds. But if you look at Figure 3 I think it is surprising that the wave formation of the small launch should be the same at nine knots as it is at twenty-one knots. If my eye is correct, it seems to undergo no change of formation as the speed is increased, the angle of the diverging wave being the same, making the same angle at nine knots as at twenty-one knots. In three of the vessels which I referred to yesterday in my paper, the angle of the diverging wave was very carefully noted at the time of the trial, and it showed a very perceptible difference as the speed increased. In the fullest of those ships it ranged from about 25° at the slow speeds to 49° at the highest speeds. In short, it was about doubled. Now, I should like to ask Mr. Froude if he considers this case to be a representative one or is a special case? If I might be allowed, I would suggest that Messrs. Thompson, at their coming trial, should carefully note the angle of the waves at the different speeds.

Mr. FROUDE. I understand you to say that the angle was more abrupt at the high speed.

Mr. J. HAMITON, jr. Much more abrupt—49°.

Mr. FROUDE. Yes; I wanted merely to make sure of the point. In replying upon this paper, I wish first to express my thanks to Mr. White for suggesting that I should prepare the paper. If it had not been for his suggestion I should not have done so. Mr. Barnaby also pressed me to do so, and it was also Mr. White's suggestion that these observations on the waves should be made with a torpedo launch model. I am not sure that otherwise I should have made them. Probably if I had been pressed for time, or there had been any doubt about it, I should have omitted them. It was Mr. White's particular request that they should be made, but I think myself that they are one of the most interesting points in the paper. I wish to acknowledge that in that respect I am indebted to him. When it was suggested to me it at once awoke my own interest in the matter. I felt exceedingly curious to know, in the first instance, what that peculiar wave is which is immediately in the wake of the launch, close to the stern. It was a surprise to me when I found it was simply the ordinary stern diverging-wave series, adapting itself to that condition. With respect to what Mr. Hamilton said, I was myself surprised to find that the angle of the diverging waves was in this case so constant at different speeds. According to the observations they seem nearly constant; but, as I mentioned in the paper, it is exceedingly difficult to say what the angle of the diverging wave is. The form it takes is that of a very small crest, which extends for some distance without increase of size; then it becomes more marked, but as soon as it obtains its maximum height it turns into a rounded shape something like a mussel shell, as I have endeavored to represent on the diagram. Certainly the general line included a minute crest which precedes the rest, and forms a curve which you cannot say has any definite angle at all. Still the positions of the crests seem to indicate that the angle of the series in this case is constant. In the launch, of which the diagrams are given there, the angle seems to be much more acute—that is to say, more nearly parallel to the line of motion—than they usually are in my experience. Possibly, if we had tried blunter models in the same way we should have got a blunter angle throughout, and possibly an angle which would have changed more with the speed. This is only a particular case, and one cannot say it would be so constant in all other cases. I quite indorse what Mr. Biles has said as to the non-appearance of the humps in the resistance curves on progressive trials. No doubt the explanation of the humps not appearing in the progressive trials is that the observations are not taken at sufficiently close intervals of speed. At the same time the speeds shown on these diagrams are higher than ships commonly attain, and the humps are not plainly marked at moderate speeds. Certainly I think that to try more speeds, and to use the revolutions as a measure of speed, would be a very in-

teresting addition to the ordinary form of progressive trial. I have felt exceedingly flattered by the remarks of Mr. Denny and of Mr. Barnaby; and, I confess, I am surprised to find the paper is regarded with so much interest. It seemed to me that it is not only theoretical, but that a good deal of it is hypothetical, and is very incomplete. You may call it dough; one may hope it may become bread some day. A great part of it requires a good deal of treatment before it can be made of practical use. I was very much pleased that Mr. Denny was struck favorably by the appearance of the curves of speed up to forty-six knots. I made out those curves for ships of moderate scale, in order that the speeds might not seem so frightening. Now I almost wish I had made them out for a larger ship, since it is considered so encouraging to see these high speeds represented.

The PRESIDENT. Gentlemen, I am sure I can convey with your approbation our united thanks to Mr. Froude for his most able paper, and we have had a most interesting discussion to follow upon it. Mr. Denny, in those very touching, and I think beautiful, remarks that he addressed to us, probably paid as high a compliment as he possibly could do to the memory of our lamented member, Mr. Froude, and to the labors of his useful life, when he told you that ship-builders think in his thoughts. It was a beautiful phrase, and it adequately described the fact. And I think that his worthy son—"the worthy son of a worthy sire"—has given great encouragement to active minds such as that of Mr. Denny himself, and his able assistant, who has addressed us with so much ability to-day. He has given them good promise that those thoughts shall not repose. Mr. Froude is following in the steps of his father, and we all know that science never stops; and it is impossible to say, if his life be long prolonged, as we all hope, to what extent he may carry those thoughts. It is also, I think, due that we should recognise publicly the gratitude of the public to the admiralty for these most valuable experiments that are being carried on upon the great subject of wave resistance. It is eminently one which is occupying the thoughts of our ship-builders more than any other at this moment, and it must be a satisfaction to all of you to have proof of such ability as Mr. Froude displays and exercises in watching and conducting these experiments. I convey, I am sure with your full appreciation, your thanks to Mr. Froude for his paper.

ON THE RUSSIAN IMPERIAL YACHT LIVADIA.

By Capt. E. E. Goulaeff, I. R. N., A. D. C., *Member*.

[Read at the twenty-second session of the Institution of Naval Architects, April 8, 1881; the Right Hon. the Earl of Ravensworth, president, in the chair.]

In bringing before you a paper on the performances of the *Livadia*, I am fully aware that the very imperfect trials and very short experience of the behavior at sea of this extraordinary vessel do not afford us sufficient data for arriving as yet at the final conclusions on the properties of this type. But this vessel has excited an unusual interest among the professional men and the public at large of this country during her construction, and has met on her passage in the Bay of Biscay with an accident which has already caused some misrepresentations, and consequently I was afraid that my silence on the occasion of this meeting might be interpreted to the disadvantage of the *Livadia*.

I beg, therefore, to be understood that what I am going to lay before you to-day is all that I consider myself justified in stating at present on the ground of facts realized for the moment, but is far from being all that I shall have to say, in support of my arguments, in this Institution on a future occasion in favor of the *Livadia's* type, when I shall be armed with data of carefully conducted trials.

Every ship is a compromise amongst a vast number of qualities, which, if carried to extremes, are incompatible with one another. No professional man will question the truth of this proposition, which, if true for a vessel of ordinary form, is the more so for a vessel of such unusual proportions as the *Livadia*, where some of the desirable qualities of an ordinary ship have been attained in a degree never before realized. It is therefore very important, and only fair, that the discussions on the *Livadia* should bear on her as a whole, and not on some particular properties separately. Consequently, it is necessary that I state to you, first of all, the aim of her designer.

As the *Livadia* had to be a yacht, it was decided to make all her qualities subordinate to the utmost safety of navigation, and to the utmost comfort depending on the possible limitation of rolling motion at sea, and on the provision of spacious apartments with a luxurious amount of light and air. As to speed, it was intended to be satisfied with 14 knots, which was the speed of the imperial yacht of an ordinary form, the unfortunate predecessor of the *Livadia*, lost in the Black Sea.

If I tell you now that the *Livadia* does possess, in addition to a double bottom, three sides, spaced not less than 6 feet apart, insuring her against all possible contingencies of stranding or collision in a de-

gree not possible to be attained in any other ship; if I tell you that her steadiness at sea, as tested in a storm last autumn in the Bay of Biscay, has proved to exceed anything that has yet been realized; if I further tell you that this ship carries extensive palaces, which were pronounced by many competent critics and by thousands of visitors who have inspected her to excel, in the size of their apartments, light and air, anything which one can expect to meet afloat; and if I add to this that her speed proves to be 15¾ knots instead of 14, as intended, then perhaps I may not be thought too bold in believing that the ship commends herself to your special attention.

It was stated in this hall that the idea which led to the adoption of the circular form in Russia, as embodied in the Popoffkas, was rather a dogma than a practical truth. But I believe it is understood by those who have devoted more close attention to the subject that it is not the circular form which is the characteristic feature of Admiral Popoff's idea, but the great breadth in proportion to the length; and few words only will be sufficient to explain the reasons which led to the adoption of proportions embodied in the design of the *Livadia*.

Extended experience in the Black Sea with the larger of our two circular iron-clads, the *Vice-Admiral Popoff*, having 120 feet beam, led the designer to adopt not less than 150 feet for the breadth of the proposed yacht. As to length and draught, consistent with the adopted breadth, these had to be determined by considerations of sufficient longitudinal stability and of proposed displacement. The length was fixed at 230 feet, which affords greater longitudinal stability than would be possessed by any ordinary ship of her length. The draught was kept at 7 feet only, in order not to exceed much the displacement, amounting to about 4,000 tons.

The construction of her hull required very careful consideration, in order to obtain throughout it the distribution of material in the most advantageous manner. No precedent of any kind yet existed to guide the framing of her specification, but that of circular vessels, built, however, for different purposes. It is evident also that no girder theory, useful only for the structural arrangements of ordinary long vessels, could be applied in this case.

Even still greater and still more complicated difficulties presented themselves in finding out the best mode of application of the propulsive power of this vessel. Besides the experiments with paraffine models, which it is now the practice of the British Government to conduct for the purpose of determination of the total probable horse-power required to drive the vessel at a certain speed, there was another model, made of steel, one-tenth the ship's size, in order to obtain some data in respect to the efficiency of the intended arrangement of propellers.

All these experiments were conducted under the guidance of Dr. Tideman, chief constructor of the Royal Dutch Navy. Their results were certainly of great value, but no one could say at the time to what extent

they were applicable to the actual ship. One of the most competent judges in this matter, Mr. Wright, chief engineer of the British Navy, in his paper "On the steam trials of H. M. S. *Iris*," read before the Institution, mentions that the application of twin screws to fast steamships has been a subject hitherto little investigated. When we remember that the *Livadia* has three propellers, arranged in a quite novel manner, and working behind the stern so differently to anything which has as yet been tried, then it will be obvious that the difficulty of the best solution of the problem to which Mr. Wright has been referring was still greater in the new yacht.

According to what was thought the most advantageous arrangement, it was decided to have three separate sets of engines, each set being designed to indicate the power of 3,500. Each of these engines was made to propel an independent screw, with its blades projecting below the bottom of the body of the vessel for about 9 feet. Experiments with a model provided with similarly arranged propelling screws have shown that in this case the augmentation of the total resistance due to the action of the screws behind the ship's stern amounts only to 22 per cent. of the total resistance, while the augmentation of resistance with an ordinary arrangement of propellers was estimated by the late Mr. Froude to be from 40 to 50 per cent.

On the first day of her official trials the *Livadia* has shown her mean speed, maintained during six consecutive hours, to be equal to 14.83 knots, with an indicated horse-power of 10,200, and on the next day on the measured mile the ship has attained the mean speed of 15.725 knots, with an indicated horse-power of 12,354.

Some years ago I was invited to bring before your notice some facts derived from the trials and experience with two small circular vessels built by the Russian Government, and then I took advantage of that opportunity to declare what I thought may be the future development of the idea when applied to the construction of larger vessels of great speed. The discussion that followed the reading of that paper, referring only to speed, showed how extremely adverse was at the time the opinion of some members as to the possibility of attaining with very broad vessels anything like high speeds. Some were maintaining the necessity of employing as much as five to six times the power to get the same speed out of a broad vessel, as compared with a ship of ordinary form.

The actual trials of the *Livadia* are at any rate sufficient to dispel all such prejudices against her form and against her breadth.

To show how very much exaggerated was the opinion entertained a short time ago on the subject of the difference of power required to drive an ordinary ship and a vessel of the type of the *Livadia*, I may quote Sir Edward Reed's statement, made on the basis afforded by the actual steam performance of the *Livadia*, as published by him in The Times (October, 1880):

	Displacement.	I. H. P.	Speed.
Penelope	4,394 tons.	4,703	12.7 knots.
Livadia	4,420 "	4,770	13 "
Orion	4,700 "	4,000	12 "
Livadia	4,720 "	4,500	12.5 "

In connection with this table it may be noticed that the engines of both ships, *Penelope* and *Orion*, are developing at the speed named their full power, whereas the engines of the *Livadia* keeping such speeds need develop only one-third of their power, consequently greater loss in overcoming engine friction and blade friction must be involved in their work. But even disregarding such considerations, the figures as they stand in the table are already sufficient to indicate that the amount of power per ton of the displacement required to drive the *Livadia* with a speed of at least 12–13 knots compares very favorably with that required in the case of an ordinary vessel of the size driven at the same speed.

This table, valuable as it is, refers, however, only to moderate speeds. I will therefore compare the *Livadia* with the *Iris*. The following table shows that the power provided in the design and actually developed on the measured mile in the case of the *Livadia* is not of extraordinary amount, as we see that ships of ordinary form and proportions were already supplied with similar power in proportion to their size.

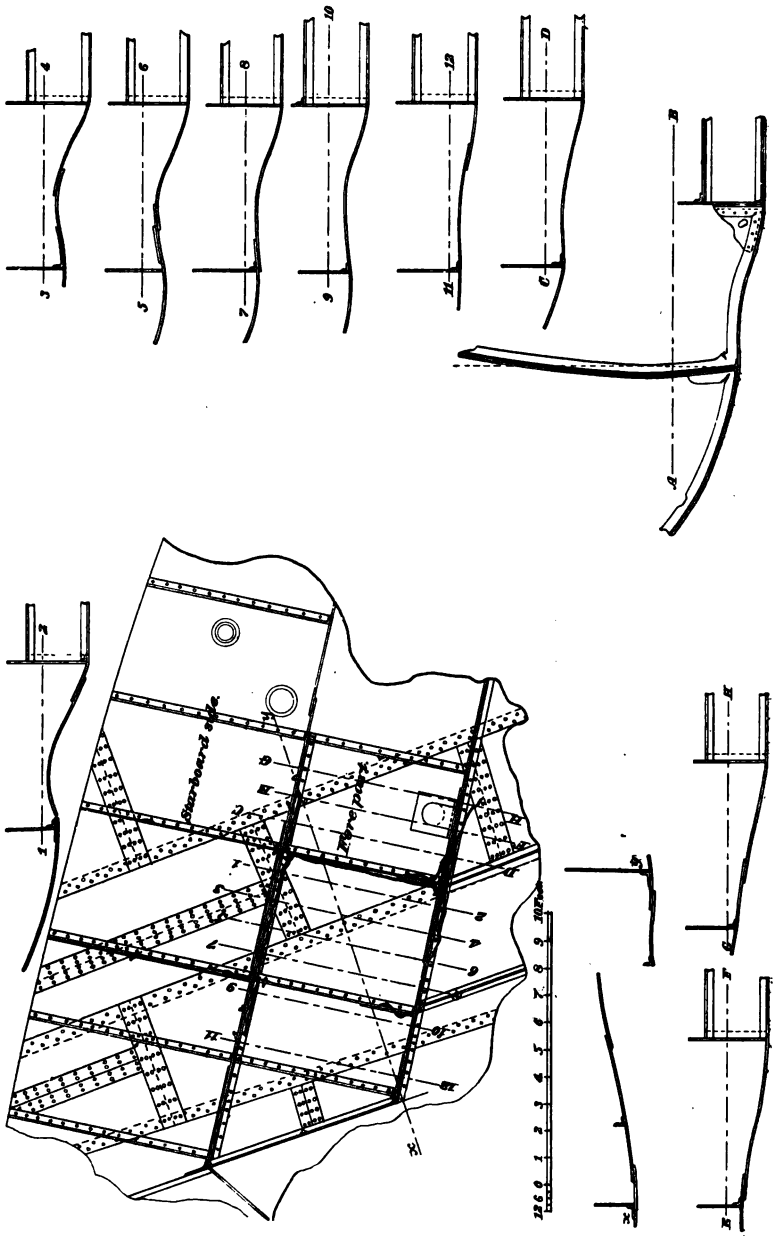
	Iris.	Livadia.	
		As provided in the design.	As actually developed by the firm.
Number of horse-power per ton of displacement	2.28	2.35	2.79
Number of horse-power per square foot of mid-area	10.71	10.50	12.35

In producing before you this table I am not forgetting that the *Iris* steamed at a rate of more than two knots per hour faster than the *Livadia*, but it must be admitted that these two additional knots were realized not at her first measured mile trials, but after exhaustive experiments with the altered screws. From this and from what I have said before, in reference to the difficulties which we had to contend with in the distribution and proper application of the propelling force in this vessel, it is evident that no fair comparison of her can be as yet drawn with fast steamships of ordinary form unless some further trials of this ship with propellers of varied dimensions and shape be made.

Also, it was made a subject of particular remark by all who have witnessed the *Livadia's* trials that scarcely any waves accompanied her motion even at the highest speed. This shows that there should not be any extraordinary absorption of power in overcoming the wave-making portion of the resistance, which is the most important source

of the expenditure of power in ordinary vessels driven at their highest speeds; but this very important question, however, can be only answered with great accuracy after further experience with this vessel.

Again, though every effort was made to secure in the *Livadia* goodness of form with the object of having no unnecessary amount of eddy-

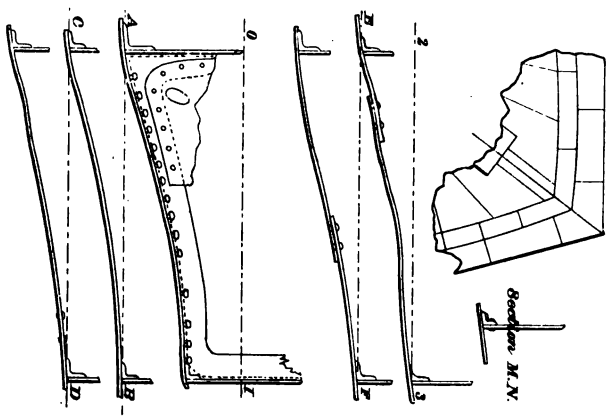


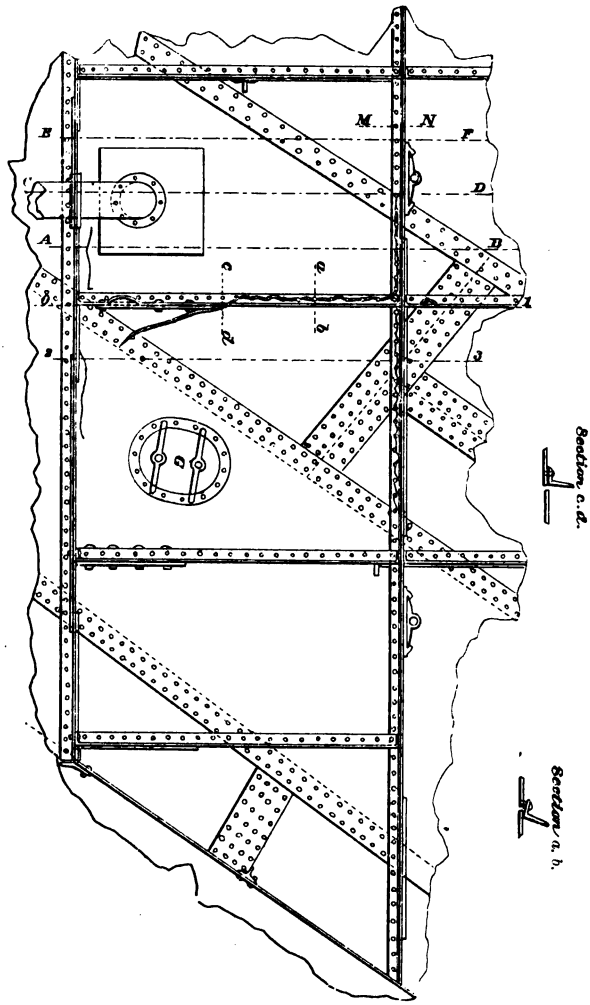
THE ACCIDENT TO THE LIVADIA; STARBOARD SIDE.

resistance, yet her design has involved so many new points that no doubt her form itself may be very much improved in vessels of similar kind which might be built in future.

To complete the consideration of the steaming capabilities of the *Livadia*, based on her trials, it is necessary to add also that these trials were conducted on the Clyde immediately after leaving the basin in which she was fitting out, and where she was lying for about four months after her launch, with no means for the proper examination of her underwater part and for cleaning it, which is usual with ordinary ships of importance before being taken on the measured mile.

As to her rolling, which we experienced in October last in the Bay of Biscay, I will make only a few observations. The rolling in no case exceeded $3\frac{1}{2}^{\circ}$ or 4°. This remarkable steadiness is due to the enormous metacentric height, insured by the great breadth. The period of oscillation, at the same time, is also very large. Such ships, as explained in an article in Nature (for July, 1880), while obeying each wave, are by that very means exempted from the tendency to accumulate the effect of a succession of waves. And, indeed, it was observed that the oscillations were often not continuous, but that the ship in inclining to one side had sometimes the motion arrested at some portion of the roll. The forward part of the superstructure divided the waves, which were met vertically in two parts, whilst the edge of the lower raft divided them horizontally, thus destroying the effect of the waves on the vessel. With the height of the waves reaching 20 to 21 feet, as was estimated





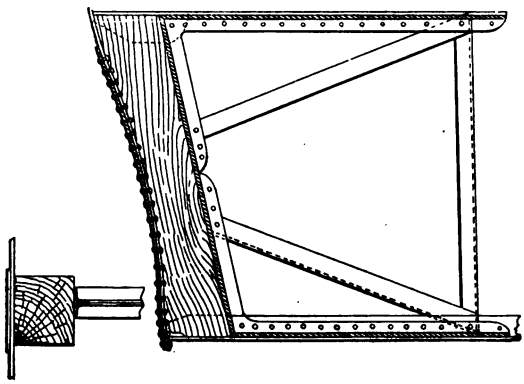
THE ACCIDENT TO THE LIVADIA; PORT SIDE.

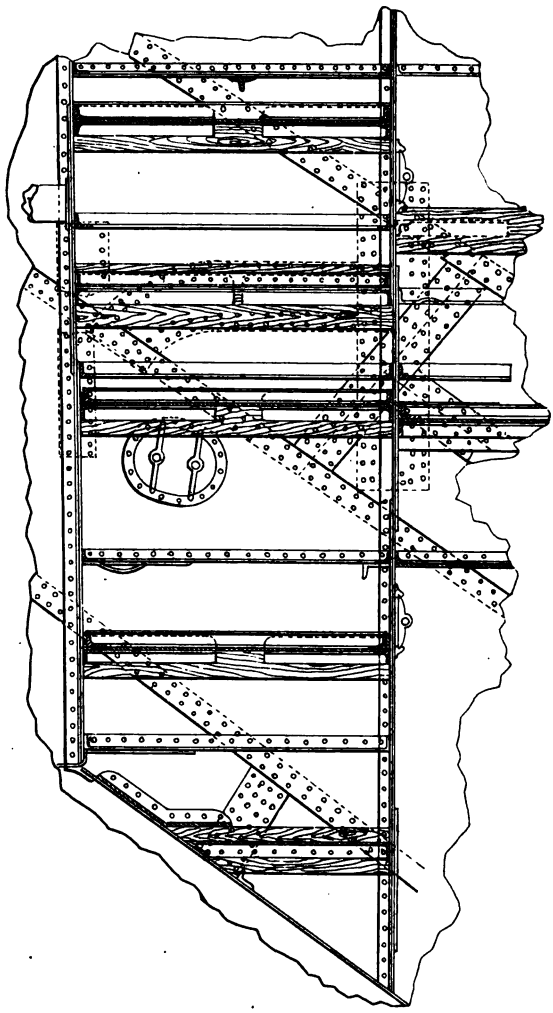
The sections showing the crippled plates are taken at distances apart of one foot, and are drawn from measurements taken at distances apart of 6 inches. The lines of fractures are laid out from ordinates taken at intervals of 2 inches between rivets and cracked plates measured accurately to $\frac{1}{16}$ inch. The lines of cracks, where below frames, are shown in full instead of dotted lines.

by Admiral Houston Stewart and Sir Edward Reed, guests of His Imperial Highness the Grand Duke Constantine on board the *Livadia*, and with our course directed head on to the sea, only an occasional spray could reach the upper structures containing the imperial apartments. I leave to much more able and more competent judges, such as Sir Houston Stewart and Sir Edward Reed, to say more of their own feelings in respect to her behavior in that severe storm.

Now, after the ship has been tested under the strain of her powerful

machinery, and under the strains which were brought into existence in a sea-way, it is satisfactory for me to be able to tell you that so much of strength has been evidently secured in this vessel that not the slightest sign of structural weakness could be perceived in any part of the hull. Also, the local strengthening in wake of the brackets supporting the shafting of her propelling screws and in wake of her machinery—having no massive cast-iron foundation—proved to be amply sufficient. This amount of strength has been secured with a quantity of material not exceeding the weight employed in the construction of any steel vessel afloat of similar displacement. The steel has been used in the whole structure with the exception of the under-water part of the outside plating, which was made of iron. The structure and joiner's work and decorations of the upper palaces stood the effect of the storm remarkably well. Altogether the execution of the whole work throughout this vessel reflects the highest credit upon the firm of Messrs. J. Elder & Co., the present head of which, Mr. W. Pearce, has spared no efforts in bringing this ship into existence by his spirit of enterprise and energy, combined with no ordinary amount of knowledge.





THE ACCIDENT TO THE LIVADIA; REPAIRS ON PORT SIDE.

Angle-irons employed, 3½ inches by 3½ inches by ⅜ inch plates of Russian iron; rivets placed in old holes.

I need not mention the splendid manœuvering qualities of such a short vessel as the *Livadia*. These are evident to the members of this Institution. Also the steadiness with which she kept her course, notwithstanding her high superstructures, was much admired by so experienced a sailor as Admiral Houston Stewart.

The only defects which were found to exist in this vessel, embodying, as we have seen, so many excellent qualities, were the unpleasant and occasionally heavy blows or shocks she was receiving from the waves in the under-water part of her bow. These blows were due, no doubt, to her small draught of water. They have given rise to the idea of

attributing to them the cause of the accident with which the *Livadia* met before calling at Ferrol. But the members of this Institution understand that there are several means of obviating such blows—common to all shallow ships when driven against very high seas.

As to the accident which resulted in the outside plating being bulged inwards and giving way in two places, with a few frames broken in wake of the bulged skin, the careful investigation of the nature of the fracture, not only by myself, but by such competent and experienced naval constructors as Sir Edward Reed and Mr. Pearce, has shown that these could have been caused by some hard substances, as the sharp pieces of wreckage, which were seen floating about the yacht on a day previous to the discovery of the injury. I submit here the plans which have been taken from the actual places.

As I said before, many not in possession of actual facts expressed an opinion that the injuries received by the *Livadia* might have been produced by the blows of the sea. Such an opinion can be scarcely correct, as from the drawings you will observe yourselves that in every instance the outside plating has given way, not in its weakest points, such as would be, for instance, the middle of the spacing between the frames or along its seams and butts, but quite the reverse, in the very strongest parts, where it is immediately supported by framing and bulkheads.

I leave to the members themselves to decide, with these drawings now before them, whether the sea can be so capricious as to produce only such action, the effect of which is restricted to the supported places, and whether the sea is capable of bending a small corner of one of the fractured plates and carrying this corner off. Doubtful to me as it is, if even such effect of the sea will be admitted within the limits of possibilities, it will still be obvious that there are several means to prevent its occurrence in future by the introduction of additional strengthening, such as stiffening the single framing of the outer cells by means of reverse-irons, diminishing the spacing between the frames from 4 feet 10 inches to 2 feet 5 inches, increasing the thickness of seven-sixteenth inch outside plating, and many other ways which have been already adopted. In any case, the injuries received were of such unimportant character that, with the thorough development in this vessel of the cellular system of construction, they did not in the least affect the safety of the ship, as with them we were steaming in a very heavy sea at a rate of twelve to thirteen knots before we got to Ferrol, and their existence was not even suspected on board by those in command of the yacht.

The small extent of the damages will be obvious also from the fact that their repair has been made without any dock, and did not require any more mechanical means than those which Captain Nogack, who commands the vessel, had at his disposal on board.

In conclusion, I may add that whatever will be the opinion of the learned members of this Institution as to the real causes of the injuries sustained by the *Livadia* when crossing the Bay of Biscay, the mem-

bers will doubtless agree that there are many ways of obviating such accidents in this ship, and certainly more in any future vessel of the *Livadia's* type, as such accidents are not dependent on any qualities inherent in this type.

In summing up, it may be said that the *Livadia* did really prove herself to possess many qualities so desirable in a yacht and yet unattainable in a ship of ordinary form and proportions, whilst the speed she has realized transfers the question of a broad ship *versus* a narrow one, for at least a good many purposes, from the field of speculative hypothesis into the field of appreciable fact.

NOTE.—For discussion see page 159 *post.*

ON THE INJURIES SUSTAINED BY THE LIVADIA IN THE BAY OF BISCAY.

By Sir E. J. Reed, K. C. B., F. R. S., M. P., *Vice-President.*

[Read at the twenty-second session of the Institution of Naval Architects, April 8, 1881; the Right Hon. the Earl of Ravensworth, president, in the chair.]

The construction of a ship of such very unusual proportions and of such large steam power as the *Livadia* is an incident in the progress of naval architecture well calculated to attract the attention of professional men. Regarded as a scientific experiment on a full-sized scale, the production and trial of this ship has furnished naval designers with information of great value which could in no other way have been attained, and I for one feel, and have always felt since the experiment was initiated, grateful to all of those persons in authority who contributed to her existence. Among those to whom this tribute of professional gratitude is due must be included the exalted personage for whom and by whose sanction she was built, and who has recently met with a cruel and violent death, which we all most deeply lament.

It is to be regretted that in this as in all experiments in naval architecture great risk is run of complicating, and even of compromising, the scientific elements of the problem by minor and accidental circumstances. Speaking as one who has been to sea in the *Livadia*, and has witnessed for himself both her performances at sea and the minor incidents of the voyage, I can truly say that I have never hitherto been willing, even for a moment, to lose sight of the scientific aspects of the problem because of the secondary incidents which have excited very much more public attention. In this Institution, however, the popular error of losing ourselves in mere matters of detail will not be repeated, and I feel confident that I may this evening dwell upon some of the structural details of the *Livadia* without reducing in any degree the lively interest you will feel in those characteristic qualities and performances of the ship which have been so well set forth in a paper by Captain Goulaeff. That gentleman has well brought before you both the steaming capabilities and the unprecedented steadiness of this extraordinary vessel, and although the data furnished by the *Livadia's* performances will probably be variously interpreted by the scientific gentlemen present, some of them seeing in them a marked success, and others drawing from them less satisfactory inferences, all present will, I think, admit that the science of naval architecture has been benefited in a marked manner by the production of a ship so signally steady in great seas, and steaming, in spite of her enormous breadth, at a speed of nearly 16 knots, notwithstanding that the steadiness was attended by unusual shocks of the sea, and the speed was produced by a very large expenditure of

power. It is not, however, my duty this evening to speak of the general qualities of the *Livadia*, and I shall pass from them, merely observing that I have noticed with much satisfaction in Captain Goulaeff's paper his promise to contribute to this Institution the results of the elaborate trials which will doubtless be hereafter made in the Black Sea for the benefit of the ship and of science.

It is proper that we here should give calm and deliberate consideration to the injuries which the *Livadia* is known to have sustained during the storm in the Bay of Biscay, and I propose to lay before the Institution with perfect frankness, and with as much fullness as the matter seems to deserve, an account both of the nature of the injuries, and the causes to which I feel obliged to attribute them. And first let me say, that any one who has observed a tumultuous sea in a storm must be prepared to learn that a ship of extremely light draught, and of almost perfect steadiness, receives violent upward blows from the ascending water, and this more especially right forward, where the onward motion of the ship naturally subjects the bow to additional violence. This certainly was the case with the *Livadia* during the gale we experienced. It is scarcely possible to describe effectively the shocks of this nature which we experienced in the bay. Some of the blows were such as produced a sensible interference with the ship's slight longitudinal movements, resulting, as it seemed in these cases, from a large wave bodily striking and lifting to some extent the bow, or, which is much the same thing, checking its downward movement when that happened to be occurring at the moment. Other shocks were of a much sharper and apparently of a more concentrated character, and produced considerable vibration and tremor throughout the hull; and much more rarely, but still repeatedly, the blow would seem to be just such as one would expect to happen from the ship striking a rock. On one occasion, or possibly on two occasions, the blow was so much of the nature of the impact of solid against solid that it was difficult to believe that the ship had not been struck, and violently struck, by some very hard and solid substance. Even floating timber could scarcely be expected to deliver such a shock upon the ship, or the ship upon it; and, as I have said elsewhere, it is difficult to believe that then at least something like the iron cross-tree of a floating mast had not struck the bottom. Now I confess that for myself, if I had had but these various shocks alone to judge from, I should, in spite of their seeming sharpness and concentrated violence, have been ready to believe that they were the effects of the sea alone. I estimated the heights of the larger waves during the worst part of the gale as quite twenty-five feet, and, as the sea was confused, there were at times crests and peaks of leaping sea, so to speak, that were obviously capable of striking under the bottom with tremendous force; and it seems to me that when a mass of water thus strikes upwards under a very flat and shallow bottom, although the outer portion of the crest or peak may crumble away under the blow,

there may be a solid central core of water, if I may so phrase it, that cannot get away, and must strike the bottom almost or quite as a huge punch driven upwards would strike it; and therefore I am prepared to believe that the sea is capable under such circumstances, and in such a case, of inflicting very concentrated injuries upon the bottom plating. And here I will at once not only admit, but declare, that around the bow of the *Livadia*, in its outermost compartments, there were injuries inflicted, as I believe, by the sea alone, and proving, as I feel sure, that there was considerable local weakness at that part.

Together with his paper, Captain Goulaeff, acting with the full knowledge and approval of Admiral Popoff—whose perfect frankness and candor in the matter we must both acknowledge and admire—has sent here tracings, in the fullest possible detail, setting forth the whole extent of the injuries sustained by the bow of the *Livadia;* and those who take the trouble to examine these drawings* will observe that all the injuries were confined to the outer rim, so to speak, of small water-tight compartments, which were considered by Admiral Popoff to be exterior to the ship proper (which is bounded by an oval bulkhead framing inside of these cells); these exterior cells being treated by the admiral as forming no very essential part of the ship, and therefore having nothing whatever placed within them. They were not in any degree utilized for storage, but merely added by their buoyancy to the floating power of the ship. Knowing, as the admiral well did, that he had divided the ship proper into a large number of cellular compartments, and that injury (either from collision, or from wreckage, or from sea) of the outer compartments could in no degree jeopardize the ship's safety, and desiring, as he naturally did, to keep the hull as light as possible, he framed these outer cells in a very slight manner. I observe that Captain Goulaeff in his paper says: "So much of strength has been evidently secured in this vessel that not the slightest sign of structural weakness could be perceived in any part of the hull." I cannot assent to this view. Of course, if Captain Goulaeff by "structural weakness" means general weakness, the objection to his observation which I am about to offer may not be well founded; but for my part I consider that both an inspection of the ship's bow cells in Ferrol, and the inspection of the drawings which we have here, give undoubted evidence of local structural weakness in this part of the vessel. My explanation of this weakness is twofold: first, the number of frames and other supports of the outer plating at this part was insufficient; and secondly, the frames and certain angle iron struts which were employed to give additional support to the outer plating were deficient of those reverse irons which we all know are absolutely essential to the development of the full strength of a ship's angle iron frame. On the first point I may observe, that as the ship is approximately circular, Admiral Popoff has seen fit to frame her

* The drawings referred to are those which are reproduced in Captain Goulaeff's paper. (See pages 146 to 150.)

radially, a system which naturally tends to concentrate strength near the central parts of the vessel, and to distribute it unduly at the exterior parts. Of course it is easy to make up the deficiency in these outer parts by introducing additional frame angle irons, and this was done in the *Livadia* to some extent, but, as I think the event proved, to an insufficient extent, and I can hardly believe that any experienced ship-builder now present will be prepared to affirm that the weakness developed under the circumstances could not have been anticipated. I think the frame angle irons in this part of the vessel were certainly too few, but I must, in fairness to Admiral Popoff, add that it was only under the exceptional violence experienced at the bow that the framing of these outer cells yielded. I went carefully through the corresponding cells at the after part of the ship, and found no sign whatever of any yielding to what must have been, even at those parts, the severe strains and blows experienced.

As regards the second point, it appears strange that any one engaged in ship construction should fail to see the absolute necessity of reverse irons upon the angle iron frames and struts. Of course it is quite possible to make a very large angle iron perform the duty of a much smaller one, even when the reverse iron is omitted from the former, but no one can pretend that this would be a good distribution of material. Admiral Popoff does not appear to share this opinion, however, for he has very largely dispensed with the reverse irons throughout the structure of the *Livadia*. All my respect and friendship for the gallant admiral are insufficient to reconcile me to this practice of his, and before the ship left the Clyde, on the occasion of my first visit to her, I remarked this general absence of the reverse irons with surprise, and made it a subject of conversation with her distinguished designer. I anticipated precisely the kind of buckling and fracture of angle irons which subsequently occurred; but what I did not anticipate was that the injury would occur as low down as it did, and be limited to the comparatively unimportant cellular spaces which suffered. I thought the flaring upper bow would be likely to receive, and to yield, more or less, to the heavy blows to which it seemed peculiarly exposed. In this respect I was pleasantly disappointed; the upper bow did not suffer at all, and great as was the derangement and fracture underneath the bow in the outer cells, it was a remarkable feature in the ship's behavior at sea that she never received (so far as I observed) any violent blows whatever upon the flaring bow of the superstructure. Notwithstanding the immense elevation of this superstructure, and the great height of its ornamental shield and crown above the sea, and notwithstanding likewise the immense buoyancy of the ship forward, the seas were at times of such a height that the bow was frequently immersed almost up to these ornaments; still this upper bow never yielded in the least degree to the waves.

Those who will examine the drawings will see a hole or two, small in

extent, and such as could only have been produced by extreme localized violence. It is these holes that were attributed to wreckage by Mr. Pearce, Captain Goulaeff, myself, and others. It is of course an open question whether it may be conceived that the sea alone could have produced them. After what I have already said, I shall not be supposed to have any desire to dogmatize upon the point. It will certainly be difficult to many to believe them producible by water only, but if any of those present should consider them so producible it is not for me to dispute the point with them. On the other hand, I can state as a matter of fact, that after a most careful examination of the holes themselves, those of us who were on board came to the conclusion that the ship must have been struck by wreckage.

There remains a few remarks still to offer. I have said that only the outer cells at the bow sustained injury. There was, however, one adjacent compartment of the ship proper that was made leaky and filled. An examination of this compartment after it was pumped out gave, however, no sign whatever of structural weakness. It had evidently been filled at its junction with one of the outer cells, and in the immediate vicinity of the largest and worst of the holes. This hole was, as you will therefore see, immediately adjacent to the bulkhead; it was also immediately adjacent to one of the angle-iron frames, and likewise to the stout covering plate, and it seems reasonable to suppose that had the sea alone produced this fracture it would have occurred at a weak part, and not at the very strongest part.

Another observation which it is fair to make is this: The *Livadia* was built by the eminent firm of Messrs. John Elder & Co. on the Clyde, of which Mr. Pearce is the responsible head. There may be those who suppose that any weakness in a ship thus built would involve, in some degree, the responsibility of the firm. It is not for me to defend or apologize for John Elder & Co., but in the case of this particular ship the responsibility for the design must obviously rest upon the Russian designers, who prepared all her drawings and specifications, and who contracted to have her built in accordance with them. I do not think it would be fair to lay the responsibility for so novel a vessel, and one of such very exceptional structural details, upon the builders. I feel confident—indeed I can state as a matter of fact—that this view of the matter is fully accepted by the responsible authorities in Russia; but in simple fairness it must also be said that if the responsibility for any local weakness, or any other defect whatever in the ship, must rest upon Admiral Popoff and his coadjutors, to them also must be attributed the merit and the praise of having conceived so remarkable a design. I have been accused, I believe, of not stating all the facts in my letters to The Times from Ferrol, and certainly I confined myself in those letters to the leading facts of the matter, and did not for a moment think of discussing in them the details of construction with which I have troubled you. The reason is obvious. So far as we professional men

are concerned the facts and considerations which I have here detailed will, I hope, be interesting, and possibly even instructive; but you will know perfectly well how to subordinate them to the larger features of the scientific experiment which this ship has so remarkably embodied. What the public were concerned with, it seemed to me, was the speed of the ship, and the marvelous steadiness with which she crossed a stormy sea. It was to demonstrate the possibility of obtaining this great steadiness in conjunction with high speed that the ship was built, and I regarded, and still regard, the question of local weakness in some structural details as one of altogether accidental and minor importance. Even as it was, and notwithstanding the fact that I laid no stress upon a few evidences of local weakness, and mentioned even the holes that were made, although with frankness, still without attributing importance to them—I say, notwithstanding this, the public have talked and written and thought apparently a great deal more about these miserable minor injuries than they have about the splendid success of the ship in all her main qualities. It is perfectly obvious, therefore, that if I had laid much stress upon the injuries, the primary qualities of the ship would have been still more neglected. But the best answer to all such criticisms is, that my object in writing upon the vessel was to give the public information of real and lasting value, and would in no degree have been served by those remarks upon technical details with which I have ventured to trouble the Institution this evening, and which, in my opinion, are as appropriate here as they would have been inappropriate and improper in the columns of the leading journal. If I have any doubt in the matter it is whether I do not needlessly exaggerate the importance of these details by explaining them even here, and now, to an avowedly technical audience.

Before concluding, I will say one word upon the proposed sheathing of the ship with wood and copper. Most of those present know that in our own navy numerous iron and steel ships have been sheathed in this manner, primarily for the purpose of protecting the bottom from fouling. Admiral Popoff has adopted the same system, somewhat differently applied, in the case of the *Peter the Great*, and of one at least of the circular iron-clads. Before the *Livadia* was built he mentioned his intention to treat her in the same manner. It is, therefore, an untrue thing to say, as some have said, that the intention to sheathe her has been conceived since the voyage across the Bay of Biscay, and for the sole purpose of protecting the bottom from the blows of the sea. How far the wood-sheathing may serve this purpose you can judge as well as I; suffice it for me to say that the intention to sheathe her was a forethought, and is not an afterthought.

In conclusion, I feel confident that I shall express the feeling of the Institution when I say that we are grateful to Admiral Popoff and his able assistant, Captain Goulaeff, for having furnished this Institution with particulars of their remarkable ship. On receiving, as I did, Cap-

tain Goulaeff's paper, I wrote to Russia to point out that, while the only drawings that were sent were those exhibiting the injuries, the Institution would naturally desire to have further drawings, descriptive of the ship herself, contributed to their records. My distinguished friend immediately telegraphed to his representative in Scotland, directing that all necessary drawings, and, if possible, a model likewise, should be sent to the Institution to illustrate the subject at this meeting (see Plate XXIV), an act of consideration for which I have not failed to return him our best thanks.

DISCUSSION.

Admiral Sir H. STEWART. My lord, I am suffering from such a bad cold that I am quite unequal to expatiate, as I should have wished to do before this meeting, on the very delightful and pleasant voyage I made in the *Livadia*. The description that you have heard, the observations and remarks as to her qualities at sea, of which alone I feel myself capable to speak, by Captain Goulaeff, and still further by Sir Edward Reed, are so full that I really could add nothing to them, except to indorse their truth. I may state that I never was in so comfortable a ship at sea in a gale of wind, and the only point at all that could be taken exception to is the very remarkable feature that Sir Edward Reed described to you—which he said perhaps I could describe better than he could, but which I certainly cannot—that as the ship rose and came down on the sea she received a heavy knock under the bottom. That was a peculiar sensation, but the absence of rolling, the easiness of the motion, the great comfort on board, and the handiness of steering were such as I have never seen before in any other ship under similar circumstances of weather and sea. Putting into Ferrol had nothing to do with any injuries received, because the Grand Duke did me the honor to consult me as to the necessity of going into Ferrol. There was no sign of the gale moderating, it was increasing, and the weather was very thick and bad. Outside the ship it was uncomfortable indeed; but in the saloon, where we were provided with an admirable *cuisine* and the electric light to cheer us, and to show us what good things were put before us, which we were able to enjoy from the entire absence of motion in the ship—inside the ship there was every reason to remain at sea, especially for those who had nothing to do with the wear and tear of the vessel. Outside, the prospect was very unpromising; there was a howling wind, a rough sea, and an angry sky; the weather being so thick that you could not see the length of the ship ahead. The Grand Duke said: "This is His Majesty's yacht, and it has cost some money; it is fitted with very expensive and very valuable furniture, and she certainly is not intended to be knocked about here in a gale of wind for no object, and if there is a port at hand we may as well put into it and wait until we

get better weather." I said, "Your imperial highness, I entertain entirely the same view. I followed the same course myself at nearly the same point of the ocean, when I was in command of a screw three-decker, going to the Mediterranean to take the admiral's flag. I saw no use knocking about in a heavy sea, and I put into Ferrol, and I made the rest of my voyage afterwards with ease and comfort and economy to the service, because I brought my ship into port without there being any necessity for making good any defects, and I should recommend the same course." The end of it was, we went into Ferrol, when I had no idea, neither had anybody on board, that there was anything the matter with the ship, and I am quite sure there was no reason to prevent the ship going on. I should have had the greatest satisfaction in taking her on to Sebastopol myself, if his imperial highness had done me the honor to ask me to do so. Having the pleasure of Sir Edward Reed and Mr. Pearce as messmates on board, I had, as you may suppose, a very pleasant time, which perhaps you may think influenced my good opinion of the vessel. I can only say, however, that Sir Edward Reed took every opportunity of investigating the height of the seas, because he went into places where I did not care to go even as an old sailor. The point where he showed you the imperial arms looks over the sea, and he went to the extremity when she put her nose down in the sea, and out to the end of those outriggers in the height of the gale. An ordinary ship would have rolled those in the water, but she did nothing of the kind; you simply saw the waves spring up like surge on an ordinary beach. Sir Edward Reed is fully competent to tell you his opinion of her behavior at sea, and all I can say is that I fully indorse all I have heard with regard to her.

Mr. W. H. WHITE. I wish, my lord, to speak on the scientific aspects of this question to which Sir Edward Reed has drawn such particular attention, and more particularly to the question of comparative resistance and expenditure of horse-power in this vessel, when put alongside of vessels of ordinary form. On the testimony of Sir Edward Reed and Admiral Stewart, there can be no question about the very excellent behavior of this vessel. It must be accepted that she was a marvelously steady, well-behaved ship, but the question is to consider, that being given, what has been the price paid for it as affecting future designs. First, I should like to say that by the courtesy of Admiral Popoff, and the kindness of Captain Goulaeff, an old pupil of mine, I have had the opportunity of looking through all the results of the experiments made by Dr. Tideman on the resistance of models of the *Livadia*, as well as the results of trials made with the large-scale model on Loch Lomond. I did this when the vessel was more like a ponton than a ship—long before her trials. Captain Goulaeff showed me every thing, and he showed me this, that with 10,000 horse-power they expected to get something over fourteen to fifteen knots speed. That was their estimate then. It was not declared, but I can say now, and I think it is worth say-

ing, that these figures were given to me at that time as their estimate, and that estimate, as Sir Edward Reed has since stated in the Times, has been reasonably fulfilled. I think, too, another thing to be noted is that in the design of this extraordinary vessel, so far away from any other form that had been built, and so far away even from the circular form—very far away from the circular form as first tried—all possible scientific skill was put into the problem. It could have been solved by no other method than that adopted, namely, by model experiments, and, as I have said, the model experiments came out successfully. They gave an indication of the power that would be required, and I think that those who were believers in model experiments before must become more than ever believers in model experiments now, in view of this extreme illustration of their value. Admiral Popoff and his assistants, in putting their trust so implicitly as they did in model experiments in the construction of this vessel, showed a very excellent example. Now, a word about the expenditure of power. First, as to the comparison with the pure circular form which Captain Goulaeff described in a paper read here some years ago. On the wall here is a diagram which was published some time ago. It represents the curves of resistance for the *Vice-Admiral Popoff* and the *Livadia*. I believe these vessels were of equal displacement, the one about 120 feet diameter—she was a circular vessel—and the other about 230 feet long and 150 feet broad. The great point of difference is in the draught and the form of the cross section towards the ends. Unfortunately, I do not think there is any diagram on the wall that gives an idea of the under water longitudinal form of the *Livadia*, but Captain Goulaeff claimed in that diagram that he had obtained 40 per cent. of saving as compared with the circular form with equal displacement when each vessel is towed, not with her own propeller working. If we go from these towing trials to speed trials where the propellers were working we find that the *Livadia* gained enormously on the circular shape, and gained because the propellers were placed much more advantageously in relation to the hull of the ship. The propellers of the *Livadia* are shown in the plan, and again in the middle-line section, but the two side propellers were many feet clear of the hull, and they were placed most advantageously for propulsion. No doubt the excellent performance was largely due to that. Supposing 40 per cent. to be the gain on tow-rope resistance, then there must have been an enormous gain in the efficiency of the propellers, due to their relative position to the hull and the easy flow of water to them. If gentlemen will turn to Captain Goulaeff's paper, in the earlier transactions, they will find the propellers of the circular ships are working behind a wall. It is nearly the condition over again of the floating batteries built during the Russian war, which performed so wretchedly as regards speed. Captain Goulaeff states the increase of resistance here due to the action of the screw was only 22 per cent., and adds that from 40 to 50 per cent.

was a good average, according to Mr. Froude's experiments, for a single propeller. Mr. R. E. Froude is here, and he will tell you better than I can, but 40 to 50 per cent. must not be accepted as fair average values for the augment of resistance. In single-screw vessels with iron hulls the augment of resistance is much less, and in twin-screw vessels it is still more reduced.

Now, I come to Captain Goulaeff's remarks about a prejudice against broad ships. If I remember the discussion rightly, it was not an objection against broad ships, but against circular ships, and Mr. Froude stated here publicly that towing a circular ship required from four to five times the power that would suffice to tow a ship of the *Devastation* type. This is not a question of breadth so much as of length in proportion to speed. I think the distinction is worth making, that Mr. Froude did not say that a broad ship might not be driven at high speed, but Mr. Froude has said the reverse of that. He has insisted that the circular ship required four or five times the power compared with the *Devastation* form. So it does. If we come to the *Livadia* form, compared with the *Devastation* form, then we find a different state of things. I have gone carefully into the figures, making estimates from various papers published as to the *Livadia* and Sir Edward Reed's figures in the Times, and I find that the *Livadia* at a speed of from fourteen to fifteen knots would require about 40 per cent. more power than the *Devastation* at the same speed, that is to say, instead of four or five times the power she only requires from 40 to 50 per cent. more, according to my estimate. The departure from the circular form has, therefore, effected a very remarkable saving, and, I think, speaking broadly, the profession is, as Sir Edward Reed says, under a very great debt of obligation to Admiral Popoff and the Russian Government for having shown us this fact: that if it is worth doing we can take an ordinary mid-ship section where the draught of water is half the extreme breadth, and turn it into a very broad but shallow section of equal area; then making similar changes in the other cross-sections, and keeping the same length and displacement, the expenditure of power required for a given speed is from 40 to 50 per cent. more than it would be in armored ships of ordinary form and designed for moderate speeds. If that is so compared with blunt-ended vessels, which are designed only for low speeds, I think that is very important. In the Times Sir Edward Reed compared the *Livadia* with armored vessels of a blunt form, intended not to exceed moderate or low speeds. Within those limits of speed the ship compares excellently with the blunt-ended form, and in some cases it only requires 25 to 30 per cent. more power. But we must remember that the *Livadia* was not intended to stop at 13 knots. She was intended to go on to 14 or 15, and she actually reached nearly 16, and at this high speed the expenditure of power is something frightful. I use the word advisedly; I do not say it may not be justified on other grounds. You are told here that the ship

made with 10,200 horse power about 14¾ knots, and with 2,000 horse power more made only a knot more. It is an enormous increase for that range of speed. In fact the *Livadia*, which was designed for high speed, is extravagant in her consumption of power at high speeds. Now let us put her alongside of unarmored ships. I have done that in several cases, and I find at 13 knots she requires twice as much power as an ordinary full-formed merchant steamer would do; she requires for the speed of 15 knots nearly twice as much power as an unarmored cruiser of equal size would do, someting like the *Boadicea*. The trans-atlantic steamers, built not long ago by Mr. Inglis, required 2,000 horse power at 15 knots to drive 2,500 tons, whereas the *Livadia* for 15 knots requires 10,000 horse power to drive 4,400 tons; another proof that in the *Livadia* the expenditure of power is very high. Coming to a higher speed still, if you put her alongside the *Iris*, I say that, although Captain Goulaeff has a little mystified the figures—not intentionally, I do not mean that at all—it comes to this, that at the top speed of the *Livadia* she requires 2¾ indicated horse power per ton weight driven, and the *Iris* is driven at the same speed for 1⅓ horse-power per ton. These are figures which deserve to be noticed. Now, speaking roughly, in all these cases the expenditure of power in the *Livadia*, as compared with other unarmored ships, is about double that for ships of ordinary forms and equal weight. Suppose we accept this comparative expenditure of power, then the question is why is that price paid, or what influence can the construction and trials of the *Livadia* have on future ship designs? Of course I do not pretend to give more than my own opinion, after some thought upon the subject, and I have naturally thought about the matter more particularly in relation to the designs of armored ships. It is a pretty open secret that in all probability the *Livadia* was a model on a large scale in more senses than one, and that the measurement of the steam power obtained in that way would have been useful in the design of larger ships. Supposing we wanted to design a new vessel like the *Alexandra*, and she was to have the form of the *Livadia*. I have worked out her dimensions, and she would have to be 300 feet long, 200 feet broad, and 12 feet draught, excluding the "dip" aft for the screws. I estimate that she would require from 12,500 to 13,000 horse power as against 8,000 to 8,500 in the *Alexandra* for the same speed. She would require 40 per cent. more power, more coal, and more weight of machinery, which would add seven or eight hundred tons weight. This is a serious addition; but another important thing which affects my mind is the fact that she would have twice the water-line area of the *Alexandra*. We are accustomed to think that the water-line area or deck must be protected by thick armor. If that principle is maintained, then I say that the *Livadia* form is a most disadvantageous one to protect, as regards the whole surface of the water-line, or the deck above the water-line, if a belt of armor is used. That is a point that deserves, in

my opinion, very serious consideration. Supposing you do get steadiness by putting on 40 to 50 per cent. more power, what do you gain beside? You gain the privilege of protecting 100 per cent. more water-line area. That will involve a very considerable weight indeed. As to steadiness, I think we can accept all that has been said about the *Livadia*. I think the records are of such a character that no one can doubt them. But is the *Livadia* the only steady ship built as a gun platform? Last night I was looking through Captain Colomb's paper on the *Invincible*. He was in the China seas in heavy weather, and he said the ship never rolled more than four degrees to the vertical. The *Monarch*, you will find, if you go through the records as to her rolling, to be marvelously steady, and so are the *Inconstant* and many other ships. As to the *Thunderer*, similar reports have been received. There are, then, in existence vessels, not having this extravagant beam, with a high reputation for marvelous steadiness, which, as Mr. Barnaby has said in his official report on the *Inconstant*, go up and down as the waves go under them in a continuous vertical motion. Those were his words. Now, what have we in these vessels besides this exceptional steadiness? We have something that the *Livadia* has not. The curious thing in the *Livadia* is that she pitched more than she rolled, she pitched five degrees to the vertical, and she rolled four degrees to the vertical—that is the maximum. Ships ordinarily pitch much less than they roll, and in bad weather can be kept head to sea. If the *Livadia* wants to be steadied she has to turn her beam round to the sea, I understand; but if the *Alexandra* wants to gain in steadiness, I presume she would turn her bow round.

Mr. R. E. FROUDE. As Mr. White has referred to me I will say a few words, first of all as to the augmentation of resistance from the action of the screw in ordinary ships. Captain Goulaeff states that my father's experiments show it to be from 40 to 50 per cent. Those figures were for a single screw ship, with rather full run, with a very thick sternpost and a very thick rudder post, and of that, 20 per cent., or something of that kind, was due apparently to the action of the rudder post and stern post only. In an ordinary single-screw ship with fine run, except for the action of the rudder post and the stern post, I think it would generally be only from 15 to 18 per cent. In the *Iris*, and some other forms of that kind, with twin screws, it is only something like 10 or 12 per cent., and it has been found to be under 8 per cent. in some cases. In reference to my father's dictum about the resistance of round ships, I do not think he said that the resistance of a round ship must necessarily be four or five times that of a ship of ordinary form, such as the *Devastation*, but he confined the statement to round ships of the pattern then under discussion, which had an upright side extending for some depth below the water, and then a sharp turn of the bilge. In the trials we made of the models of the Russian round ships we found an enormous improvement from trimming them by the head, so as to bring

the turn of the bilge (as Sir Edward Reed says, we may consider the end equal to the sides in these ships) at the after end almost out of the water. Instead of having a perfectly flat bottom and a sharp turn of the bilge and an upright side, if a round ship is made with gentle lines rising like a dish, with fine buttock lines, so to speak, I do not see why the resistance should be anything so very great, or anything much more than the skin friction. Certainly it is not *prima facie* a bad form so far as wave-making resistance is concerned, because all the displacement which is in the middle of the ship is almost in the condition of a submerged body—it is almost out of the reach of the surface of the water. Provided that you keep clear of the eddy-making, which is the great bane of the original Russian round-ship designs, there is no reason why you should have a very excessive resistance. I think at that time it was supposed that to alter the designs of those original Russian ships in that direction would have sacrificed the small perimeter, and consequently the small length which was to be protected by armor, and so defeated the main object of the use of the circular form.

Mr. JOHN. My lord, I will not detain the meeting more than a minute or two. I would say, in the first place, that as far as the *Livadia* is concerned, I have not had the pleasure of seeing that ship, and I have not seen her drawings, except those which have been passed round to-night; but I would mention that the *Livadia* is not the first ship as to which there has been any doubt whether the injuries arose from striking wreckage or from blows of the sea. I have a case in my mind, and I see the owner of the vessel in the room, besides several other people who saw the ship, which was a remarkable instance. She was a sailing ship of good form and very strong. That ship came into the port of London, and I heard of the injuries she had received. I was told that she had not struck any wreckage, and I must say I could not believe it, and I went and saw the ship. One of the outside plates on the bow was cracked; there were half a dozen frames inside broken; the upper deck stringers of the ship and the plates in the ship were bent down as far aft as the foremast, and the only evidence we could find of its having been the result of an extraordinary blow of the sea was this, that there was not a sign on the paint-work of the ship that showed contact with a solid body, and there was no sign, so far as the captain and officers of the vessel knew, that she had struck anything. That was a remarkable instance, and I have seen since other instances of most remarkable damage done to vessels which have been at sea for years, and have come into port damaged by exceptional blows of the sea, in a manner which if I had not seen them I really could not have believed.

Captain CURTIS, R. N. I suggest that those peculiar blows may have been due to the air confined in the water, and the ship striking on the water comes in contact with the air cushioned, so to speak, on the wave. That may account for those curious shocks. Perhaps some other gentleman, more scientific than myself, will explain whether that is possible.

Mr. LIGGINS. I can relate two remarkable cases in my experience where vessels have been struck, not by wreckage, but by impediments that they have met with in their course, and, strange to say, although years elapsed between the two circumstances, both of them arose within sight of the same spot. One was to a nobleman's yacht of 200 tons, when racing in a gale of wind against a very fine schooner off Ryde, in the Isle of Wight. She was accused by the schooner of having passed on the wrong side of a buoy, which was disputed by those on board. It would have disqualified her for the prize. The subject was investigated by the Royal Yacht Squadron Committee, and, strange to say, the day after, when that yacht was carefully examined by those interested in the success of the other vessel, the paint marks and the scratching marks of the buoy were clearly seen on the side of the bow of the yacht, which was clear proof that she had gone on the wrong side. Therefore that shows that the marks are sometimes to be traced by the paint being rubbed off onto the copper and other scratches that were visible. On another occasion, I was myself standing on the starboard side of a 300-ton schooner, the *Livinia*, in a race from Cherbourg to Ryde. The weather was exceptionally bad; one cutter was totally dismasted on her way, and a very fine cutter also engaged in the race did not arrive until ten hours after the yacht in which I was, which was the successful winning yacht. This circumstance occurred at midnight, in very bad weather, when it was blowing and raining very hard. We had to pass on a given side of a moored vessel, which was distinguished by three lights, off Ryde Pier. We were accused the next morning of having sunk a four-oared gig which had taken the committee from Ryde on board this moored vessel. We utterly denied it. I denied it, because I knew perfectly well from standing on the deck of the yacht that it could not have happened, so far as I thought, without my knowing something about it. Having gained some experience from the examination of the copper on a previous occasion, I was induced to row in a boat round the yacht, and then, to my great astonishment and to the surprise of all who were with me, the pilot and captain as well, we found we really had struck the boat, for there were the scratches and the black paint rubbed off her visible on our copper, which proved that we had struck her. The boat was lost, and the owner of the yacht considered it his duty to pay for that boat. Therefore in two cases important results arose with regard to the decision of doubtful matters, in consequence of those investigations, which test might, if applied in this case, have set to rest all doubts as regards the *Livadia*.

Mr. KIRK. My lord, as a piece of general information, might I ask what Lloyd's numeral might be for a vessel of this class, so that we might see how the scantlings would be regulated?

Mr. JOHN. I might mention, in explanation, that I do not know what her numerals would have been, because no application was made for

her class, and I can only say that had there been we might not have had this discussion to-night.

Admiral DE HORSEY. I should like to ask Sir Edward Reed if he will be kind enough to tell us how far from the central line those small blows were found on the bottom, because in the letters that were in the Times there was a question raised whether it was not probable that the screw would have been injured if she had been struck by wreckage, but looking at the extreme beam of the ship, unless the blow was given very near the central point, it would be reasonable to suppose that the wash of the sea would have sent the wreckage clear of the screw. It did not appear to me that non-injury to the screw was any evidence of its not being wreckage. To judge of great things from small, those who have been long at sea can have no doubt about the enormous blows given to a flat-bottomed ship coming down on the sea. I can tell you of what happened to me in a boat in very heavy weather. I was obliged to go to my ship, which was three miles to windward, and I got the sail-maker to put a fourth reef in before I started. I reached my ship, but on making the last tack she came down on a sea and split the garboard strake from the bow to the stern. If that would happen in a boat, why should it not happen in the *Livadia?* Mr. White, I think, has observed that it was a strange thing that the *Livadia* should pitch more than she should roll. That does not appear to me at all remarkable, viewing her proportion of breadth to length. I think if they put screws on the broadside of the *Livadia* and force her broadside fifteen knots, they would find that she rolled then more than she pitched.

Vice-Admiral SELWYN. My lord, as I have been for some time past an advocate of the spoon-shaped broad ships, I think I may fairly ask a few questions on this subject. I have seen during all my observations of flat-bottomed vessels of whatever kind, from the canal barge upwards, the moment you take them into disturbed water then what is complained of in the *Livadia* immediately occurs. I have long ago settled in my own mind, from various observations made for the purpose, what is the cause. With a bow shaped so as to allow the sea to pass under it no such action takes place, but the instant you make anything short of the gentle curve that should be there, properly calculated to take the sea clean under the bottom—if you make a sharp turn of a bilge or of a bow, the same thing occurs as with a flat vessel, she lifts to the sea by dint of her buoyancy, the sea passes under her, but continues its downward course, and leaves, what I might almost call, if it were not an incorrect expression, a vacuum under the flat part of the bottom. The instant that is felt the ship strikes on the sea invariably, and everybody who chooses to watch it in a barge with an ordinary swell on the Thames may see it going on. Sir Edward Reed has pointed out, and, I think, very fairly, how very small a consideration this injury is, and how very easily such things might be avoided and the vessel strengthened. I should like to have brought forward as a fair comparison the cubical

contents of that vessel with the horse-power that drives her. I should like to see her measured by some other rules for tonnage than those which will give an utterly false idea.

Sir E. REED. The tonnage in the paper is displacement.

Vice-Admiral SELWYN. It is quite different; but I am going on. The horse-power drives a ship whose cubical contents enable her to carry weights which cannot be carried in any other vessel of that draught, or anything near it. Those weights are the armor (a very small portion of armor is necessary) and enormous quantities of heavy guns, something far beyond what was ever thought possible in any other form of ship; she carries these weights without the slightest danger or difficulty. Those weights were represented to a certain extent by the superstructure of the *Livadia*. But I would beg to point out, as I have done before in this Institution, that if a ship (as Sir Edward Reed has also said) fulfills the purpose for which we want her, it matters very little indeed how much fuel she takes to do it, because we can easily bring down the fuel expenditure. That is not a difficult thing at all. That has been done, and is being done every day, and can be done to a much greater extent. But what we cannot do is to carry twenty 80-ton guns instead of four with any degree of safety, and if I had a ship of that character—I do not say of that shape—Heaven forbid! which can meet a gale of wind as she has been described to meet it by Sir Houston Stewart, then I say that that vessel carrying twenty 80-ton guns would be a formidable opponent for two or three ships carrying only three or four each. If you take the rate at which those guns could be fired you will easily see what an enormous advantage she would have. There are other advantages which I have spoken of at this institution before, and which I hope to see carried out. The day is coming, I am convinced, when we must go more in the direction of broad vessels—vessels occupying a position on the surface of the water, instead of the narrow type of vessels which are liable to turn over, vessels which are only able to go, before they come to the point of vanishing stability, to an angle of forty-five degrees and nothing over. That is not the type of vessel that we shall continue to build, and whatever the objection of naval architects may be to the change now, I look forward to the time when they will be as ready to pursue it as they are now to condemn it. I say confidently that these experiments can be tried easily and expeditiously. I have been at work designing a yacht at this moment which will have some 590 tons cubic contents with 130 of displacement, and she will carry an 80-ton gun on board her with the greatest ease and comfort, with one foot more draught of water forward than what she now draws. You may consider her as a gunboat if you like; she is a model on rather a larger scale than those of which gentlemen have spoken already. I hope she will be considered a model. But I wish one thing to be stated here (because I have not yet seen it stated in any paper on the subject), and that is, the real wetted surface of this ves-

sel. I have not seen it, and therefore I am not able to compare the horse-power accurately for this type of vessel. I am quite aware it is much larger, and that the calculation of speed must be made with reference to that enlarged wetted surface. With regard to the midship section, I think you will find, as compared to the weights carried in every direction, it is not at all excessive in any sort of way. I recollect hearing at the United Service Institution the late Mr. Elder speak particularly on the question of these circular vessels. He said if they are allowed to assume the shape of a segment of a sphere (I do not think he recommended that exclusively), then the towing power required does not differ for similar displacement tonnage—they are exactly the same. There were two vessels, one of ordinary type, the other the segment of a sphere, and he towed them at the end of a rope from the stern of a vessel without a single atom of disturbance of the scale-beam which he used; therefore I think I may say that there is something in the future for this extraordinary type of vessels, but I hope at the same time I shall never see in the English navy a vessel built with such a section as that. It may be very nice for some purposes, but I should deny altogether that she is fit to serve as a type for a man-of-war; still she has read us a great lesson, which I, for one, hope that all naval architects—I am sure we sailors shall—will take to heart.

Mr. MARTELL. My lord, I have only a word or two to say on this subject, and that is, that I do not think any naval architect in this room, if he had such a design as this put before him—that is, judging from the men I see around me—would have any doubt whatever as to the failure of this ship in having sufficient structural strength under the circumstances in which she was placed in a heavy sea. There is no doubt for the purpose for which she was intended, as a floating palace, the design is most beautiful, affording space and accommodation of every kind. But we know from our experience that with plating only seven-sixteenths of an inch thick, as shown here, and those plates supported by frames 4 feet 10 inches apart, it is perfectly impossible in heavy weather to prevent, when the vessel is rising and falling, the plates buckling and panting to some extent, as appears to have been the case in this instance. We have a somewhat similar system of construction with our cellular bottoms, where we have found from experience that though we have the frames larger than those, and reverse frames as well on the top of them, and have them 24 inches apart, this panting and blowing of the plating takes place, and we have gradually altered in ships according to their sizes the stiffening found to be requisite to prevent this action from taking place. I do not think we need feel any doubt as to the cause of the accident, because we know from our knowledge of the construction of ships such as this it was very likely to take place if the vessel met with heavy weather, and was just what might have been expected. There is only one other remark. I would merely say I do not think myself that such a system of construction as

this, and as shown from the investigation made by Mr. White, would be at all likely to supersede our ordinary form of ships for general mercantile purposes. He has shown that it would not do for war ships. There are so many objections to it for iron-clads, and I am sure there would be equally as many with regard to the great expense and other considerations for mercantile ships, as compared with the present system of construction, that I cannot see the advantage to be gained by its taking the place of the ordinary form of ship. I regret that I appeared to offend Admiral Popoff at Glasgow when I told him that was so. But I still entertain the same opinion as I did then. There is only one question which I should like to ask Sir Edward Reed, and that is as to the effect of a beam wind when the ship is on a lee-shore and compelled to steam slowly. I should like to know what effect that would produce. I apprehend that that would be a very serious consideration as affecting the weatherliness of a ship of this kind, drawing so little water as she did.

Mr. BARNABY. I should like to say that I think Sir Edward Reed has to-night done us justice in the statements he has so carefully put before us concerning this ship, and I think you will feel that he and Sir Houston Stewart have done justice also to Admiral Popoff and his great boldness and originality, for which we all owe him our thanks because he has succeeded in showing us much we were hardly able to find out for ourselves. But there is one point about which I remember having a conversation with Sir Edward Reed before the ship went away. He told me, if I remember rightly, he fancied that there would be some movement of the lower body of the ship, the turbot, as it is called, due to its shallowness, and I have been curious to know whether that really happened, and whether there was anything remarked in the behavior of the upper structure of the ship which indicated at all that there was a want of rigidity in the lower turbot form of the ship. I think, excepting that point, we have had brought before us to-night nearly everything that we felt curious about. I am sure you will all have felt, too, that the very important question of the power required for this form of ship has been very rightly raised and mentioned, and very wisely and properly dealt with, as I think, by Mr. White. There are considerations, as you are fully aware, that have been in our minds all through, causing us, although we are concerned in making ships to carry very huge weights, and to be very steady, to abstain from following the lead of the Russian constructors. Those considerations have been well stated by Mr. White, and you are capable of judging what weight they have. With regard to the remarks of Admiral Selwyn, I should just like to say that I have unfortunately something to do with weights involved in carrying 80-ton guns, and I can assure him if he tried to mount a single 80-ton gun he would require for that gun, its carriage, its slide, its projectiles, and its powder, over 200 tons, and if he took twenty of them he would have more than 4,000 tons to carry; that is, he would

require the entire displacement of the ship to take nothing but the twenty guns, to say nothing of the ship herself, her engines, fuel, or anything else.*

Mr. PEARCE. I regret very much I was not here at the time when this discussion commenced, so as to have heard the papers of Captain Goulaeff and Sir Edward Reed. I am quite sure, however, that Sir Edward must have disabused the minds of a great many of the gentlemen here with reference to the damage to the *Livadia* sustained on her voyage across the Bay of Biscay. He will have told you that the rent is not ten feet long and a foot broad, as has been reported and widely published by our journals in this country. He might have told you—I do not know if he has—that the ship proper has not been injured at all. The ship proper I call that part of the ship that is formed by the second bulkhead from the outside edge; the other part is simply put on to give a form to the ship. The ship proper is intended to carry the weights and all the vital parts of the ship; the outside portions were not intended to carry anything, and they might all of them have been injured in the same way that these one or two compartments were injured forward without doing the ship an atom of harm. She might have gone across the Atlantic as well with the whole of these compartments filled with water as she would if none were filled; and I am sure of this, that had this ship been sent by any private individual to the Crimea you would never have heard of this accident until the vessel arrived at her port of destination. I never could understand why the ship put into Ferrol, and why she was kept there, but I say that she had no right to put in, and it should never have been reported that any injury had occurred to the ship, because the injury was of an exceedingly slight character. From what I heard I conclude it has been stated that this ship was not fit for war purposes, and I would like to make a remark or two upon that. I do not know the basis of the argument which has been brought forward against its being suitable for war purposes, but I am quite sure that a great desideratum for a war ship is to get a steady platform, and I am also sure that this ship has the steadiest platform of any in the world; and I am satisfied that she will average, for the power, a very fair speed. The designer of the ship is surprised at the speed she attained, and I say that if some, if not all, of her elements are adopted for the war ships of our navy, we shall find them to be a great deal better than the ships which we have at present, because I look upon it that if you are going to fight very big guns you must necessarily have a steady platform; and when you consider that this ship passed through the Bay of Biscay during a week when it is recorded

* The following explanation has been forwarded by Vice-Admiral Selwyn: I desire to explain that in my paper of last session I showed a total weight of armament 4,500 tons for eight 80 and eight 100 ton guns, sixteen in all, so that I was, even then, fully aware of what Mr. Barnaby observes, and allowed an average of 289 tons per gun.—J. H. SELWYN.

that more ships foundered than in any week during the whole of last year, you will understand that she must be exceptionally steady, and as a matter of fact she rolled only three degrees one way and four degrees another, and the range of pitching was only ten degrees. I am sure that no vessel in our navy could have passed through that sea without rolling at the least twenty-five or thirty degrees, and if a steady platform is of any advantage at all it is of great advantage for war vessels intended to fight heavy guns.

Mr. RAVENHILL. My lord, I would just ask two questions: One is whether Sir Edward Reed can, in his reply, tell us if any examination was made of the appearance of the paint on the outside of the damaged plates, and in the neighborhood of those plates, on her arrival in Ferrol? The other is, if he is enabled to contradict and dispel a rumor which has been afloat—I dare say he may have heard it as well as myself—that continuous pumping had to be resorted to after the accident, and if such continuous pumping had to be maintained even after her arrival in harbor.

Admiral Sir H. STEWART. Sir Edward Reed may remember that I said to him in the course of conversation that I should like to remind the navigation officer when he makes his land fall, from the structure of this vessel he might expect to get to leeward of his point, and if I navigated her I should be inclined to make an allowance for this; and when she did make land she was rather to windward of her point; she had no lee-way at all.

Sir EDWARD REED. My lord, I am afraid that I shall have to travel very rapidly over the ground I have to go, in order to answer the questions put, and make the remarks which seem necessary, but I shall endeavor not to be long about it. With regard to Mr. Ravenhill's question to begin with. As to whether we had any examination of the outer paint of the ship's bottom at Ferrol, I can only say that we had no information as to the outside of the ship's bottom except such as was sent up by a Spanish or Russian diver, and for my own part I never believed any message they brought up at all. I soon found I could not trust to what they said, and I do not believe there was any opportunity of making an examination of the paint. With regard to continuous pumping, I believe that there was a good deal of pumping carried on. I should not like to say anything offensive to my esteemed friend Captain Linden, but it must have been carried on for Russian purposes purely; the object was not manifest to me. The water in the ship was entirely confined to four or five of those bow cells and one compartment of the ship proper, which, as I explained in my paper, was leaking. Certainly I was disturbed several times at night by hearing the pumps going, but when I inquired the next morning I could not find out why, but I believe the reason why it was done was that before we went into Ferrol I found there were some on board who did not want to leave it for a long time. I believe that is the reason why they pumped, and did a great many other things which otherwise would be quite immaterial.

Admiral Stewart has answered one question—I forget who asked it—most effectually. I remember very well the conversation which he referred to. He thought most naturally the ship would have made a substantial amount of leeway, considering we had the wind a good deal on the beam—more or less. He expressed his surprise that she had developed no leeway at all. I mean to say that any departure from her exact position was so small that it might have been due to the steering or anything else. Now some very large points have been opened up in this debate, but I think no one can possibly either complain of any part of it, or fail to see that it has been most valuable and instructive. With regard to what fell from Mr. White, I should only like to say, not by way of correcting him at all, but by way of explanation, that certainly I did take ships of not any very great speed in the comparison I gave. I thought it would be a very interesting thing to everybody to know at what sort of expenditure of power the ship was driven at a moderate speed, and therefore I took ships of quite a moderate speed, the *Penelope* and the *Orion*, and I selected the worst ships I could find among iron-clads to compare her with, and I thought that even with those ships she would compare badly, but I was very much surprised when I found she compared so well with the *Penelope* and the *Orion*—as to which latter I will not say any more, because my friend Mr. Samuda is the designer of her, and I believe she is a most admirable vessel, but still not a vessel of high speed. With regard to the economy of fuel, I think Mr. White gave a very true representation of the price which is to be paid for the other qualities of the ship. But I think, my lord, the *Livadia* suggests to us another opportunity for remembering that ships do not exist for any single purpose, they exist for a great variety of purposes; and with regard to this particular vessel I think I am repeating what some one said very truly, that the consumption of fuel really was a matter of very minor importance, because she was a yacht for the Emperor of Russia to use when staying at his country palace at Livadia, in the Black Sea, and it was not to be expected that the Emperor of Russia was likely to make many voyages in her; he would only want to go to sea occasionally, therefore it would be a matter entirely of indifference whether she burnt more or less fuel when she was making an occasional short Black Sea passage. Consequently, the matter which is of supreme importance in mercantile transatlantic steamers was of no importance in her. Of course, at the same time, it was a proper and necessary scientific inference to draw. Her form and other circumstances connected with the vessel were demonstrated not to be available for commercial purposes. But it has been truly said—I do not know whether by Mr. White or Mr. Froude—that the leading feature of this vessel is her great beam, and not the proportion of her beam to length; because I have heard repeatedly, and I think the gallant Admiral (Stewart) will bear me out, because he must have heard it repeatedly, in the conversations in the *Livadia* with the Grand Duke Constantine and Admiral Popoff, that if they had be-

allowed to build a much larger vessel they would not have made a much broader one, but would have increased the length; they had got all they desired in respect of breadth, and I must say, having regard to the minor importance, the almost insignificance, of the fuel consumption for the purposes of this vessel, there was obtained in her what you would not obtain in any vessel of ordinary form, that is, a palatial spaciousness of saloons, and galleries, and corridors, which was very suitable indeed to an imperial yacht, on which naturally at times would be entertained a large number of distinguished persons, which you could not possibly obtain in a vessel of the ordinary form, because if you made her ever so large you naturally would have to traverse a long distance in the fore-and-aft direction, which would not be convenient. We did see on one occasion, and I am sorry to say Admiral Stewart had left the ship at that time, the real character of the ship brought out when the Grand Duke entertained the naval authorities at Ferrol, when the whole ship was lighted up with the electric light, and all the features of the imperial yacht were displayed to their advantage; and I am bound to say that although you might save fuel by building a ship of the ordinary form, I defy anybody, with a ship of ordinary size and form, to have got anything like the accommodation and palatial grandeur of the character which was developed on that occasion. Mr. White drew a comparison between this ship and the *Alexandra*, and there have been several remarks made about the bearing of this on the construction of iron-clads. I feel a difficulty in that, because we have given up building iron-clads. I am not saying that reproachfully to anybody, because I was the first to do it. There was a time when we built iron-clads. I consider the *Agincourt* was an iron-clad, and I think a very foolish one, because she was so immensely long in proportion to her breadth. We now armor only part of our ships. We have dropped armor gradually from one part and another, and therefore we have ceased to be driven as we should be driven, in producing really an armored ship, to the shorter and even to the circular form. I have made some calculations in times past, and I cannot dwell upon them—it would be improper to do so—but it would be equally improper to say nothing about the point after what has been said. But I think it right to say that if you require to build an armored ship, and pass away from our present conception of an armored ship, which I take to be incipient and temporary, and only the very beginning of sea-fighting ships, and consider what you may have to produce and may be willing to produce hereafter, in the shape of armored ships carrying, I will not say the armament that the gallant admiral suggested, but a very powerful armament indeed, then I can tell you this, and I say it positively, that if you require to build an armored ship with thick armor, to carry a heavy armament, and to go at high speed, you cannot do other than build her circular without losing advantage in point of economy in fuel. When I say circular, it is necessary to bear in mind I do not mean of necessity an absolute circle, because you can always economize by making minor modifica-

tions to meet contingencies; but you must bear in mind that circularity of horizontal sections do not at all mean the form of the Popoff. They are exposed, no doubt, to the many objections stated to-night by Mr. Froude and Admiral Selwyn and others, but I think Admiral Selwyn ought to know that in these vessels the bow lines are formed after what he would call the spoon shape. There is no drawing on the wall that shows that, as Mr. White pointed out, but as a matter of fact it was the characteristic feature developed from the experiments of Mr. Tideman that operated largely in the production of this vessel; both the bow sections and the bow lines are very sharp and curve upward. Mr. White made a very true remark about deck armor. As regards deck armor he does not quite put it in the form in which I put it, and if you would allow me I would say this. As regards deck armor it does not in the least matter what the form of the ship is, whether she is a long ship or a short ship, because the deck armor being her horizontal area, covers the same horizontal area of displacement, whether you put it on the deck of a long narrow ship, or on the deck of a broad and short ship.

Mr. WHITE. My statement was that in the *Livadia* enlarged to the *Alexandra* size, the deck area would be twice as great as in the *Alexandra* herself.

Sir E. REED. That is what I say. Mr. White is perfectly right in making that remark, and I am supporting his view when I say that one of the disadvantages of resorting to an approximately circular form is, that when you use deck armor as your main element you get to a very large surface of it, and get it for no earthly purpose, because you do not relieve your resistance and improve the speed of your ship by so arranging it; but when you come to side armor, then the question of the form of the ship enters into the question in a very different manner.

It is impossible to answer the question of Admiral Selwyn about the wetted surface of the vessel at present. That will be brought out in the experiments that have to be made in the Crimea, which will be contributed to this Institution, as has been stated by Captain Goulaeff. Mr. Martell was quite right, no doubt, my lord—at least I think so—in saying that Lloyd's would not, and I am quite sure the builders of the ship would not, have arranged the frames of this vessel as they were arranged. They had to build to a specification which was furnished to them. No doubt this ship was designed by Admiral Popoff too lightly as regards the cells. Mr. Barnaby asked a question of considerable moment touching the transverse rigidity of the turbot proper, so to speak. I think Mr. Pearce will bear me out when I say that there were signs of transverse bending—the movement was not very great, but there were signs of that, and I remember going round the ship afterwards with Captain Goulaeff for the purpose of suggesting to him some little additional strengthening. We then went into the question, and I was quite satisfied that there had been some working as between the turbot deck and the understructure, and some additional strength

might with advantage be placed there. I do not think I have left any important question unanswered, and I will thank the Institution if you will allow me, on behalf of my friends, Admiral Popoff and Captain Goulaeff, for the kindness with which this paper has been received and discussed. I should say in fairness to myself, that I had no more to do with the *Livadia* than any other gentleman in this room beyond making a passage in her. I never saw her until she was afloat. I never examined her designs, and I knew nothing about her more than that; but as Admiral Stewart was pleased to pay Mr. Pearce and myself the compliment, I may confirm the Admiral's statement to the effect that he was perfectly ready, and I am sure he would have been more than pleased, if time had allowed him, to have gone on with the ship to Sebastopol. I do not go so far as Mr. Pearce altogether in condemning the going into Ferrol, which I was, perhaps, as sorry for as he was; but I think Admiral Stewart's explanation of that is perfectly satisfactory, and I know it to be quite correct and true. But I would wish to condemn as emphatically as Mr. Pearce, and with all respect for my Russian friends, what I consider to have been the very ill-advised detention of the ship in Ferrol. The ship should not have been detained in Ferrol. It is a presumptuous thing, of course, for us to say that, speaking of the property of another country and of people who knew a great deal which we did not know; but from the point of view of the sea and the circumstances, and as far as the ship herself was concerned, there was no reason whatever why she should have gone into Ferrol except to protect her from needless trial and damage at sea in a storm, which as Admiral Stewart says, is never desirable in any kind of ship, and certainly still less with her, but there was no sufficient reason for her remaining there. I can say that when I saw the last of the ship at Corunna (Mr. Pearce and I left the ship at Corunna), it was with considerable regret that we saw her steam back, not because there was any sea to prevent her going on, but on a lovely calm morning she went into the harbor of Ferrol there to lie, and unnecessarily to bring discredit on herself.

The PRESIDENT. It only remains for me, gentlemen, to do that which I am sure you will allow me to do, which is to offer to the gallant Captain Goulaeff and Sir Edward Reed our united thanks for the two most interesting papers which we have heard read about this most remarkable vessel to-night. I hope the unprecedented attendance in this hall denotes plainly the immense amount of public interest that is concentrated upon this remarkable type of ship, and I hope the large audience which I have now the honor of addressing have not been disappointed either with the papers or the able discussion that has followed upon them. I have only to ask your permission to return thanks to Captain Goulaeff and Sir Edward Reed for their papers, and to those gentlemen who have so largely assisted in enlightening us on the subject.

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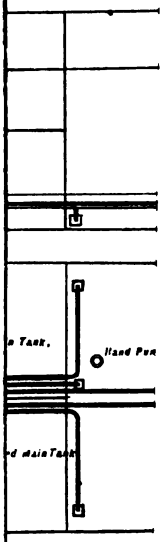

eck. Fig. 2.